

The Reliability of an Isometric Test Based on Constant Perception of Effort

Shane Michael Kilburn, B.Sc.

Submitted in partial fulfillment of the requirements for the
Degree of Master of Science in Applied Health Sciences
(Kinesiology)

Supervisor: Stephen Cheung, PhD

Faculty of Applied Health Sciences
Brock University
500 Glenridge Ave
St Catharines, ON

JAMES A GIBSON LIBRARY
BROCK UNIVERSITY
ST. CATHARINES ON

Shane Michael Kilburn©June 2009

Abstract

To date there is no documented procedure to extrapolate findings of an isometric nature to a whole body performance setting. The purpose of this study was to quantify the reliability of perceived exertion to control neuromuscular output during an isometric contraction.

21 varsity athletes completed a maximal voluntary contraction and a 2 min constant force contraction at both the start and end of the study. Between pre and post testing all participants completed a 2 min constant perceived exertion contraction once a day for 4 days.

Intra-class correlation coefficient ($R=0.949$) and standard error of measurement ($SEM=5.12$ Nm) concluded that the isometric contraction was reliable. Limits of agreement demonstrated only moderate initial reliability, yet with smaller limits towards the end of 4 training sessions.

In conclusion, athlete's naïve to a constant effort isometric contraction will produce reliable and acceptably stable results after 1 familiarization sessions has been completed.

Acknowledgements

I would like to thank my supervisor Dr. Stephen Cheung for his support, guidance, and understanding throughout this endeavor. His mentorship approach offered an extremely high level of personal independence and allowed for a lot my input to be integrated into the project. I know that my future success will positively influenced by my work in the environmental ergonomics laboratory. I would like to personally thank Michael Taber, Bill Gittings and Natalie Dies for their input and positive influence on both my project and time spent at Brock University. Lastly, to the support staff centered on the students at Brock from upper levels to the administration I have greatly appreciated all of your generosity and support over the last two years. The support received from my family and friends during my academic career have been very inspiring, thank you.

Table of Contents

List of Figures.....	vi
List of Tables	vii
List of Abbreviations	viii
Glossary	ix
1 Chapter One: Introduction.....	1
2 Chapter 2: Review of Literature	5
2.1 <i>Neuromuscular Control of Human Movement.....</i>	5
2.1.1 <i>Motor Unit Characteristics.....</i>	6
2.1.2 <i>Measurement of Neuromuscular Function</i>	7
2.2 <i>Perceived Exertion</i>	11
2.2.1 <i>Transmission of Neural Afferents</i>	12
2.2.2 <i>Cortical Representation of Peripheral Stimulation</i>	13
2.3 <i>Constant Effort Contractions</i>	14
2.4 <i>Optimal Feedback Control.....</i>	15
2.5 <i>Teleoanticipation.....</i>	16
2.6 <i>Justification for Statistical Analysis</i>	19
2.6.1 <i>Calculations.....</i>	20
3 Chapter 3: Purpose and Hypothesis.....	23
3.1 <i>Purpose.....</i>	23
3.2 <i>Hypothesis.....</i>	23
4 Chapter 4: Methods	24
4.1 <i>Participants.....</i>	24
4.2 <i>Equipment Set-up.....</i>	24
4.3 <i>Familiarization</i>	25
4.4 <i>Experimental Design.....</i>	27
4.4.1 <i>Maximal Voluntary Contractions</i>	28
4.4.2 <i>Indicator exercise.....</i>	29
4.4.3 <i>Product Exercise – RPE Clamp</i>	29
4.5 <i>Statistical Analysis.....</i>	30
5 Chapter 5: Results	32
5.1 <i>Data Screening</i>	32
5.2 <i>Maximal Voluntary Contraction and Indicator Exercises</i>	32
5.3 <i>Product Exercise.....</i>	33

6	Chapter 6: Discussion	40
6.1	<i>Summary.....</i>	<i>40</i>
6.2	<i>Reliability of the Constant Effort Contraction</i>	<i>40</i>
6.3	<i>Force Production during the Product Exercise.....</i>	<i>41</i>
6.4	<i>Changes in Physiological Measurements</i>	<i>45</i>
6.5	<i>Changes in Psychological Measurements</i>	<i>46</i>
6.6	<i>Practical Considerations and Future Directions</i>	<i>46</i>
6.7	<i>Limitations</i>	<i>48</i>
	Appendix 1	50
	Appendix 2	51
	Appendix 3	52
7	References	53

List of Figures

<i>Figure 1. Anatomical Locations of the Brain Regions Associated with Motor Patterns as Seen from the Sagittal view of the Left Hemisphere</i>	<i>2</i>
<i>Figure 2. The Interpretation of Potential Results from a Voluntary Contraction when using the Interpolated Twitch.</i>	<i>9</i>
<i>Figure 3. The Utility of Current Methods used to Assess Neuromuscular Activity.</i>	<i>11</i>
<i>Figure 4. A Cerebral Schematic Outlining the Progression of Motor and Sensory Signal Transmissions during a Voluntary Movement.</i>	<i>16</i>
<i>Figure 5. Overview of the Experimental Design</i>	<i>28</i>
<i>Figure 6. Bland Altman Plots and LOA for the Product Exercise.....</i>	<i>36</i>
<i>Figure 7. Relative Change in Torque between Successive Days of a Constant Effort Contraction</i>	<i>36</i>
<i>Figure 8. Pattern of Force Profiles across Individuals during the Constant Effort Contraction.....</i>	<i>37</i>
<i>Figure 9. Comparison of Actual and Perceived Torque during a Product Isometric Contraction.....</i>	<i>38</i>
<i>Figure 10. Self Efficacy Prior to a Constant Force Isometric Contraction.....</i>	<i>39</i>

List of Tables

<i>Table 1. Limits of Agreement for the Product Exercise</i>	33
<i>Table 2. Guidelines for the Further use of Constant Effort Isometric Contractions</i>	48

List of Abbreviations

ANOVA = Analysis of Variance

CNS = Central Nervous System

CV = Coefficient of Variation

EMG = Electromyography

FT = Fast Twitch

ITT = Interpolated Twitch Technique

LOA = Limits of Agreement – Absolute Reliability

MD = Minimal Difference

MVC = Maximal Voluntary Contraction

n = number of people

r = Pearson's Product-Moment of Correlation

R = Intraclass Correlation coefficient – Relative Reliability

RPE = Rating of Perceived Exertion

SEM = Standard Error of Measurement – Absolute Reliability

SMT = Supra-maximal Twitch

ST = Slow Twitch

VA = Voluntary Activation

VO₂ = Volume of Oxygen

Glossary

Afferent: Relates to signals that are sent from the periphery to the CNS

Central Governor: An integrator of both local and peripheral afferent information, it also acts as the point of determination for deviations from the initial efferent output via the reference signal

Closed Loop: A process that feeds back into itself and therefore creates a continuous loop

Efferent: Signals sent from the CNS to the periphery

Feedback: A physiological process where some of the original feed-forward process is fed back into the subsequent output

Feed-Forward: A physiological process that utilizes an anticipatory effect in order to produce a specific function in advance of an alteration that would otherwise cause deviations from homeostasis

Homeostasis: The maintenance of biological processes to maintain equilibrium about a particular value

Indicator RPE: The use of perceived exertion to indicate the physiological strain and stress created by the exercise

Interpolated Twitch: Determination of peripheral fatigue with the administration of a single electrical stimulus to an active motor nerve or muscle where the supplementary force produced is used to determine the residual capacity of the peripheral contractile elements

Isometric: A contraction where the length of the musculo-tendon unit does not change

Open-Loop: A process that does not feed back into itself

Product RPE: The use of perceived exertion to control the physiological strain and stress for an exercise bout

Reliability: The consistency of a measurement to describe a test for a given researcher

RPE Clamp: see product RPE

Supra-maximal Twitch – Determination of peripheral fatigue by the administration of a supra-maximal electrical stimulation to the motor nerve creating a tetanic contraction in a resting muscle

Tetanus (Tetanic Contraction): The level of force at which the frequency or number of neural impulses produce the maximal amount of tension in a muscle fibre

Voluntary Activation: The quantification of central drive to the muscle during a maximal voluntary contraction. It is determined by the quotient of a single supra-maximal electrical stimulus to the muscle during a maximal voluntary effort and following the maximal contraction

1 Chapter One: Introduction

Cerebral processes associated with voluntary movement require coordination and integration of signals from a variety of sources that possess unlimited patterns of processing. Consider the voluntary movement of your finger – a very common task used in various experimental designs. Preceding all movement is the conscious effort to activate your finger. From here millions of neurons in the pre motor cortex (PM), primary motor cortex (1M), supplementary motor area (SMA), cerebellum and basal ganglia cooperatively select and organize a movement pattern based on your current environmental conditions and intent (Roland et al. 1980). Figure 1 displays the anatomical location of each area except for the basal ganglia which is located within the interior of the brain. Each areas has millions of individual neurons that must work together to produce a coherent movement pattern.

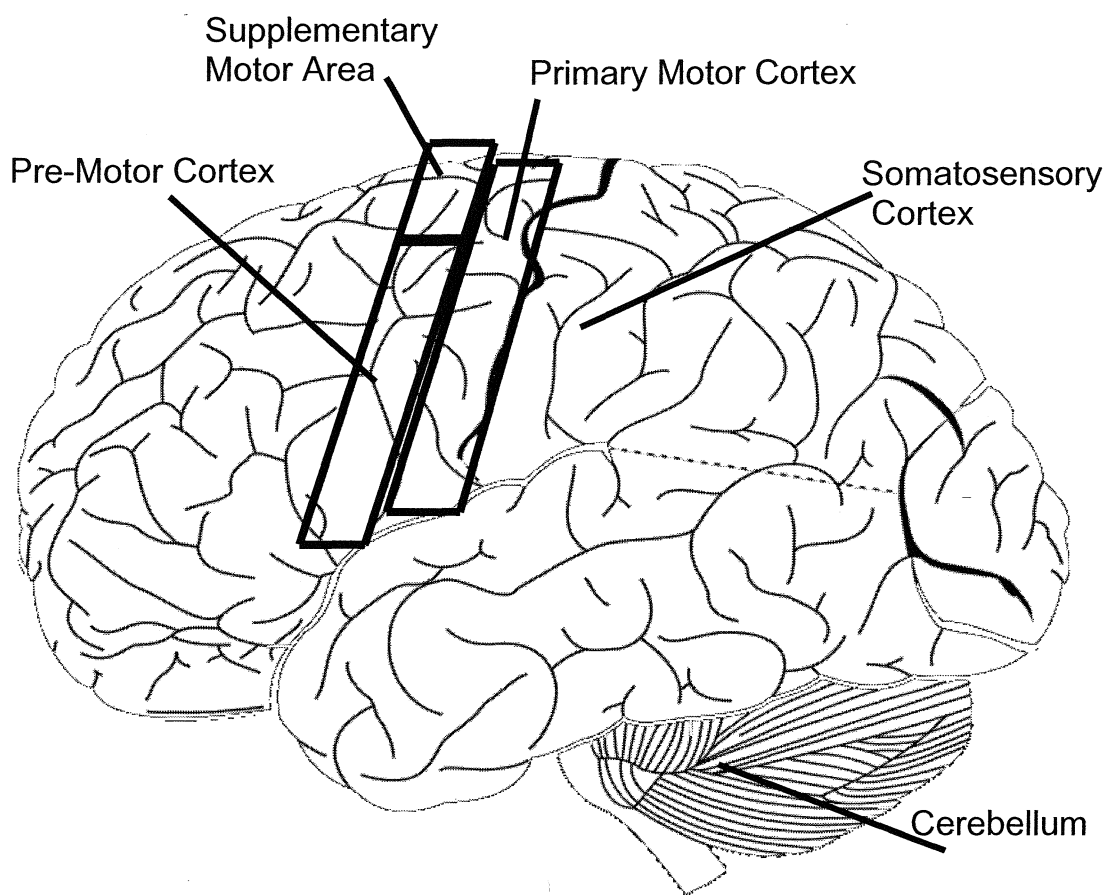


Figure 1. Anatomical Locations of the Brain Regions Associated with Motor Patterns as Seen from the Sagittal view of the Left Hemisphere

While there is no awareness of these internal preparatory processes it is important to have some indication of their subjective influence on performance. Post event interviews commonly find athletes saying something to the effect of “I just wasn’t in it today”. The rating of perceived exertion (RPE) was designed to quantify the subjective magnitude of physiological stress during exercise. It is commonly accepted with the scientific literature that a high agreement exists between increased RPE and increased physiological parameters such as heart rate, sweat rate, and lactate (Borg et al. 1987; Pandolf 1978). Signals that initiate in the peripheral system and terminate in the brain are thought to be integral in

the sensation of effort. This afferent feedback is a continuous process and is not limited to that of movement parameters.

Homeostasis is based on the general maintenance of several biological systems functioning as a collective unit within a specific range, and is based on multiple sources of sensory input. Furthermore, it has recently been proposed that awareness of our homeostatic state in conjunction with anticipatory processes can reliably predict exercise output during aerobic activity. Within this model of teleoanticipation several brain indices, currently unknown, predetermine the magnitude for muscular activity and regulate energy output as a function of homeostatic maintenance (Noakes 2007). Within this context Noakes has proposed that the subjective interpretation of effort is capable of regulating exercise, and it does so solely to maintain homeostasis.

Cain and Stevens (1971) were the first to use a constant effort contraction in order to determine the function of force related cues on further force development and how fatigue influenced these contractions. Force development demonstrated two consistent temporal changes (i) an initial sharp decline followed by (ii) a slow but steady reduction (Cain, Stevens 1973). Further assessment and interpretation lead to the speculation that biological parameters outside the muscle were responsible for the initial sharp decrease and processes inside the muscle accounted for further slow reductions (Cain, Stevens 1973; Pandolf, Cain 1974). Additional results utilizing EMG during a constant effort contraction are inconclusive. Abraham (1975) found a decrease in torque and EMG while Emes (1979) demonstrated a reduction in torque with a steady EMG. Any increase in the electrical signal from the muscle has been determined to demonstrate muscular fatigue as more motor units are recruited, and may be associated with changes in perceived exertion. It should be noted that all previous research participants had their initial torque set to the desired magnitude before visual cues were removed (Pandolf, Cain 1974; Abraham, Craig 1975; Cain, Stevens 1971; Cain, Stevens 1973; Emes 1979; Jones, Hunter 1983). A weakness in all research subsequent to Cain & Stevens (1973) is the reliability of their measurement. To this date no quantitative analysis has been

performed on the subjective rating of one's perceived exertion to produce a reliable outcome. When subjects are simply required to attain a specific muscular force based on perceived exertion their force for brief a period, 3 – 5s, produces a high reliability within moderate ranges of intensity, moreover no data exists on sustained contractions (West et al. 2005).

The complexity of analyzing movement increases as more of the body is utilized therefore; drawing conclusions from whole body exercise is much more difficult than it is from isometric contractions. While interpretation of isometric data has been able to determine causational and mechanistic results they are not always applicable to whole body performance. Several authors have demonstrated that increases of core temperature are the primary contributor to ongoing decreased VA throughout isometric contractions in the heat (Morrison et al. 2004; Thomas et al. 2006). This data demonstrates a clean relationship between core temperature and the ability to voluntarily activate individual muscles. Unfortunately, this relationship is not as easy to analyze during exercises such as running or cycling. Pandolf and Cain (1974) demonstrated that force production during static isometric handgrip contractions displays similar changes as a function of time with that of power output during cycling. Yet, currently there is no strategy to extrapolate the results of alterations in neuromuscular function from simple movements to whole body coordinated movements involving multiple joints.

Providing the body has a mechanism to anticipate workload prior to exercise it may be possible to accurately control neuromuscular output using only perceived exertion. Moreover, the anticipation of workload may hold true under all types of physical movement, being isometric and/or whole body exercises. Using a constant perceived exertion this protocol will directly address the highly relevant gap in the scientific literature surrounding the extrapolation of conclusions drawn from isometric contractions to those of whole body exercise.

2 Chapter 2: Review of Literature

2.1 Neuromuscular Control of Human Movement

This literature review presents techniques and limitations surrounding the control and quantification of voluntary force output. It is then followed with a proposal to determine the reliability of a method to control isometric exercise intensity by maintaining a constant perceived exertion. If reliable this process will be further used for the manipulation of neuromuscular function within different isometric environments. The benefit of constant perceived exertion is the ability to subjectively manipulate any intensity of effort with any range of muscle groups. This includes the manipulation of neuromuscular output during static and dynamic exercises. In addition, it is possible to perform static and dynamic exercises at the same perceived exertion. Therefore, we speculate that when exercise is controlled with perceived exertion it will create the possibility to study the connection between isometric and whole body performance.

To control voluntary movements several brain regions are thought to have a specific role where the organization of these processes creates the particular movement. Neural transmissions from pre-central regions including the primary-motor cortex (1M), supplementary motor area (SMA), pre-motor cortex (PM), cingulate cortex and cerebellum initiate excitatory information that is subsequently sent to the motor neuron (Nelson 1996). At the motor neuron an electrical signal is induced and the information is transferred to numerous muscle fibres, the contractile units of a muscle (Sherwood 2003). This collection of a motor neuron and all of the muscle fibres that it innervates is termed a 'motor unit'. Ultimately, when the electrical signal is transferred across the neuromuscular junction, an action potential is propagated along the muscle fibres generating a chemical response and contractile activity.

2.1.1 Motor Unit Characteristics

Within our body there are two main types of muscle fibres, slow twitch (ST) and fast twitch (FT); the latter can be further subdivided into FTa and FTx depending on their ability to re-synthesize ATP through oxidative phosphorylation (McArdle et al. 2001). Both ST and FT fibres exist in every muscle within the body, yet certain muscles have a larger proportion of one type depending on their primary roles (Elder et al. 1982). Contractions requiring maximal amounts of force generation primarily rely on FT fibres. FT muscle fibres display higher rates of shortening and increased levels of force production, yet fatigue much quicker. Prolonged isometric contractions lead to a marked decrease in the number and amplitude of active motor units, leading to fatigue of the muscle (Fallentin et al. 1993).

Our body has internally developed two approaches to develop a resistance to fatigue, (1) motor unit recruitment patterns and (2) motor unit firing rate; where both of these are controlled by the brain (Kayser 2003). During very low intensity sub-maximal isometric contractions, systematic control allows for alternate motor units to be stimulated giving each unit time for recuperation (Fallentin et al. 1993). As the resistance is increased the body has two options: recruit more motor units, decreasing the pool for alternating recruitment, or increase the firing rate of the active motor neurons (McArdle et al. 2001). The 'size' principle implies that slow – small diameter and fatigue resistant – contracting motor units are activated prior to rapidly – large diameter and fatigue susceptible – contracting motor units based on their respective fibre diameters (Henneman 1957). Providing all motor units are capable of being voluntarily stimulated, any subsequent increases in central drive to the muscle during a sub-maximal contraction will reduce the number of available motor units, and the time to volitional exhaustion. Such physiological responses led researchers to pioneer innovative methods to determine how the body regulates exercise output.

2.1.2 Measurement of Neuromuscular Function

Voluntary effort requires the coordination of multiple motor units. While the previous principles will directly apply to activation of single muscles, the relationship is much more complicated during whole body exercise. During a voluntary effort it is unknown whether the reductions in contractile activity are limited by a cardiovascular, energy supply, neuromuscular, muscle trauma, biomechanical, thermoregulatory, psychological / central governor model, or if it is a combination of these (Abbiss, Laursen 2005). A typical method to determine the manifestation of fatigue involves a maximal voluntary contraction (MVC) used at periodic time points throughout the experimental manipulation, but with this protocol differences between central and peripheral contributions remain undetermined (Bigland-Ritchie et al. 1986). Popular techniques to localize the site of failure are based on electrical stimulation of the motor nerve, an approach used to mimic the central drive from the brain. If a muscular contraction is stopped and a stimulated contraction is performed on a resting muscle this is called a supra-maximal twitch. If a single stimulation is administered to the muscle during a contraction (maximal or sub-maximal) it is called an interpolated twitch (Merton 1954). These procedures allow for the indirect determination of peripheral and central factors associated with fatigue (Gandevia, McKenzie 1988).

2.1.2.1 Supra-Maximal Twitch Technique

Supra-maximal twitch technique involves the comparison of the torque created during a train of maximal electrical stimulus applied to the motor nerve of the resting muscle, and the torque created with a MVC (Merton 1954). When the MVC is capable of eliciting the same amount of muscular activity as the electrical stimuli it is assumed that all motor units can be voluntarily activated. Initial results demonstrated that a voluntary effort was capable of maximally stimulating the muscle. Supra-maximal twitches are based on the assumption that if both maximal voluntary effort and maximal stimulation of the nerve coincide with a progressive reduction in muscle contractility that peripheral restrictions are the

primary cause of fatigue. Limitations to the supra-maximal technique do exist: (i) pain caused to the subject through its administration (ii) the technique stimulates all of the motor neurons and does not represent sub-maximal efforts (iii) the technique cannot be applied to muscles where the motor nerve is not easily accessible (Bigland-Ritchie et al. 1986). These limitations led to the development of alternate techniques with less potential constraints.

2.1.2.2 Interpolated Twitch Technique

As the previous technique does not allow for interpretations of active musculature the interpolated twitch technique (ITT) was introduced to mimic central drive to a muscle during an isometric or isokinetic contraction (Merton 1954, Newham et al. 1991). The technique involves an electrical stimulus to the active muscle, and is capable of increasing the muscular output if not all muscle fibres are active. If an increment in force is not seen then it is assumed that the voluntary effort was capable of recruiting all motor units and is termed maximal voluntary activation (VA). On the other hand, when the stimulus creates a visible twitch, voluntary force was unable to maximally stimulate the muscle as all the motor units were not fully recruited or were firing at sub-optimal rates (Todd et al. 2003). The size of the twitch from an active muscle with respect to that in a resting muscle is used to calculate the voluntary activation (Merton 1954). The larger the increment in force created by the stimulus during a maximal effort the larger the reduction in central drive and thus a reduced VA (Figure 2). Therefore, while ITT uses a twitch force to determine peripheral fatigue the calculation of VA for a maximal contraction determines central fatigue (Taylor, Gandevia 2008). A major limitation to the calculation of VA is that it is only applicable to isometric and isokinetic contractions and therefore cannot give direct information about the alterations that accompany whole body exercise (Newham, McCarthy & Turner 1991).

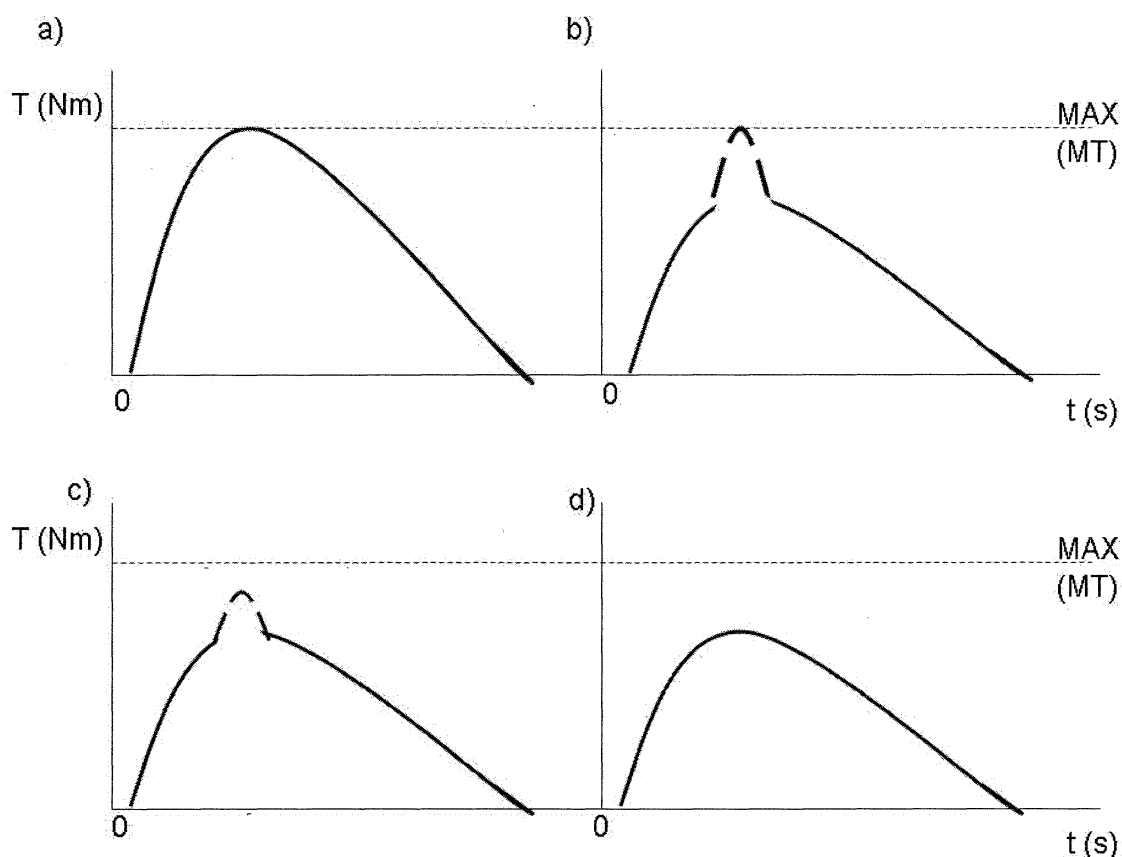


Figure 2. The Interpretation of Potential Results from a Voluntary Contraction when using the Interpolated Twitch. — Force tracing; - - - Increase in Force due to ITT; MT, maximal torque; T, Torque; t, time. a) no fatigue and maximal voluntary activation b) central fatigue and decreased VA with no peripheral fatigue c) central and peripheral fatigue paired with decreased VA d) peripheral fatigue only with maximal voluntary activation.

2.1.2.3 Electromyography (EMG)

EMG estimates central drive by indirectly measuring the magnitude and frequency of electrical impulses to quantify the recruitment and frequency of motor units respectively. EMG electrodes can be classified into different categories based on their location and configuration. Electrodes can be located on the surface of the skin, or inserted into the muscle (Fallentin et al. 1993).

Surface EMG electrodes simply adhere to the skin, superficial to the muscle of choice, and are simple to administer. For this reason they are very popular, but this simplistic approach comes with limitations. The fat and skin located between the muscle and electrode contain various amounts of conductivity (water) that alter the signal of the motor unit action potential. A variety of limitations depending on contraction type, muscle chosen, and electrode placement are combined with the possibility of relative movement between the muscle and skin during a contraction (DeLuca 1997). The variety of limitations surrounding EMG continues to be a strong argument against its use in a dynamic environment. On the other hand, indwelling electrodes are inserted directly into the muscle parallel to the direction of the muscle fibres, removing most of the previous limitations discussed with surface electrodes. As this technique requires a more sterile/invasive approach its use in various settings is limited. The second feature of electrodes deals with their configuration, mono-polar or bi-polar. Mono-polar arrangements are only capable of measuring a single signal and are therefore, less used within more recent literature due to the inability to differentiate between signal and noise (Nigg, Herzog 1999). Bi-polar arrangements allow for the determination of potential difference to be quantified. The collection of a signal at 2 points along the muscle allows for the filtering of common noises as the potential difference is compared to a ground electrode for the acquisition of EMG recordings (DeLuca 1997). The recording of a consistent and clear signal is a difficult task in highly controlled isometric settings, therefore its use as a marker of activation during whole body exercise is not recommended. Unique approaches have been designed to quantify the results into a meaningful description of neural drive that can be related to force output; they include but are not limited to integrated EMG, root mean square, wavelet analysis and power frequency (Nigg, Herzog 1999). As location, configuration and the purpose of the research will dictate the type of analysis undertaken readers are referred to an excellent review for further explanation (DeLuca 1997). In summary, EMG remains a viable method to measure motor unit recruitment when applied in a

carefully designed and static environment. Figure 3 offers an interpretation for the utility of different measurement techniques in multiple environments.

Location of Measurement	Device	Isometric	Isokinetic	Whole Body Exercise
Central	TMS	★★	★★	★
	EEG	★★	★★	★
	ITT	★★★	★★★	
Peripheral	EMG	★★★	★	★

Figure 3. The Utility of Current Methods used to Assess Neuromuscular Activity. An overview of the techniques used to define the location of neuromuscular fatigue. TMS – Transcranial Magnetic Stimulation; EEG, Electroencephalography; ★, rating of utility, 3 stars are equivalent to an excellent utility in that environment.

2.2 Perceived Exertion

The perception of exertion is an important tool used to assess an individual's awareness of physical strain. Originally, perceived exertion was developed to be an indicator of intensity during work or exercise; the use of perception in this fashion is termed an 'indicator tool' (Borg 1982). Increasingly within the literature, perceived exertion has been used to prescribe exercise intensities; the use of perception in this sense is termed a 'product tool' (Buckley et al. 2000). The importance of perceived effort lays in its potential to assist in the understanding of the effects that afferent information has on exercise intensity, and their adjustments to the sensation of physiological stress. One of the largest benefits of setting exercise intensity with a product tool is that subjects are capable of

continuously adjusting their energy output in order to maintain a desired perceived effort. The advantage here is that afferent information is capable of providing real time influence on performance. Throughout exercise the changes in both metabolic and cardiovascular measures are thought to subconsciously feedback to the brain where they are integrated to (i) alter the motor plan sent to the working musculature in an attempt to optimize energy expenditure, and (ii) stimulate conscious awareness of the physiological strain (Mihevic 1981). Thus awareness of physical strain may continually influence performance in a manner that safely guards physiological processes from potential failure from over exertion.

Most often applied, is the 15 point category scale (ranging from 6 – 20) designed to increase linearly with exercise intensity, heart rate, and oxygen consumption; because of this, it acts like an interval scale where the difference between each value is equivalent (Borg 1982, Noble et al. 1983). As perceived exertion is associated with factors indicating fatigue, a prolonged activity at constant work intensity will cause a predictable increase in RPE (Doherty et al. 2001). A differentiated RPE protocol has been suggested where readings for local, central and overall RPE are measured (Ekblom, Goldberg 1971). Participants are asked to rate their perceived exertion for each level independent of the others. This technique potentially allows for a more precise examination of the interactions between local and central factors. Direct comparison of a measurement may determine how individual responses can vary across populations.

2.2.1 Transmission of Neural Afferents

Central coordination of complex actions relies on a variety of sensory input from multiple sources – eyes, vestibular system, joints, skin, and muscles (Sherwood 2003). It has been shown that while humans lacking proprioceptive inputs are able to initiate movements, they have difficulty performing normal multi-joint actions (Sainburg et al. 1995). Two separate types of sensors exist in the musculo-tendon unit; muscle spindles and Golgi tendon organs which are

sensitive to changes in length and tension respectively. Primary spindle fibre sensory input plays an important role in our movement patterns. Frequency of action potentials from the primary afferents increases with muscle lengthening, informing the 1M the magnitude and direction of limb movement (Roll, Vedel 1982).

Located within the elastic fibres of the tendon are the sensory afferents that relay the muscle's tension (McArdle et al. 2001). When the extrafusal fibres of a muscle contract, they exert a strain on the Golgi tendon organs and elicit a highly reproducible firing response that is proportional to the muscle tension (Binder et al. 1977). This afferent information of force generated in the muscle is associated with the conscious sensation of discomfort, it is thought to be sent to the brain for processing, allowing for both safe and coordinated movements (Gregory et al. 2002).

2.2.2 Cortical Representation of Peripheral Stimulation

After initiation and transfer of peripheral sensory signals towards the brain, multiple cortical regions become responsible for their integration and processing. Interestingly, many of the regions active during the motor output stage of voluntary movements are also active during movement perception. Naito et al. (2002) proved that the 1M is active during stimulation of the muscle tendon despite not receiving any direct sensory input. Furthermore, the primary and secondary somatosensory areas, traditionally thought to be involved solely in perception, are also active during motor output (Mima et al. 1999; Naito 2002; Prinz 1997). The dual role of each area is highly affected by the level of activation, potentially controlled by the cingulate cortex (Naito 2002). A high level of activation is indicative of an increased signal reception/creation and therefore conscious perception. In addition, the level of activation is thought to be set prior to movement where extremely fast actions dictate a lower level of activation (Naito 2002). Given two tactile stimuli of equal intensity, subjective perception of pressure will be lower during exposures where the intensity is known prior to touch (Blakemore et al. 2001). In order for such a fine level of control over

activation of sensory cortices prior to muscular action a predictive mechanism must be present.

2.3 *Constant Effort Contractions*

As mentioned above, the RPE has also been used as a subjective 'product tool' whereby one can control exercise intensity with the perceived exertion. Results from independent laboratories support the theory of using RPE to control exercise at a variety of intensities (Cain, Stevens 1973; Buckley et al. 2000; Ceci, Hassmen 1991; Dunbar et al. 1992; Dunbar et al. 1996; Eston et al. 1987; Eston, Williams 1988; Robertson et al. 1979). Conclusions drawn from the use of individual muscles demonstrate that the higher the perceived exertion used to maintain isometric torque, the faster the rate of decline in muscular tension (Cain, Stevens 1971). Typical force-time profiles for a constant effort contraction display an initial exponential decrease followed by a more linear decline (Cain, Stevens 1973; Pandolf, Cain 1974). With the use of ischemia following the sustained contraction, Cain and Stevens (1973) were able to determine that structures outside of the muscle were responsible for the initial decline, and that the linear reduction in muscular tension was to maintain EMG at a steady level. As subjects were instructed to maintain a given perceived exertion, the result of constant drive to the muscle was seen as an indirect measure that it was correlated with perception. The electrical activity of the muscle associated with constant effort contractions indicates an initial stage where new motor unit are recruited followed by change in rate coding (Cain, Stevens 1973). While these results demonstrate initial attempts at sourcing the origins of afferent signals, only one study has manipulated the sensory signals to determine their influence. Abraham & Craig (1975) utilized the idea of reduced afferents with a pre-cooling protocol and a constant effort contraction; while no consistent tension-time pattern was found the reduction in afferents had no effect on tension decline.

2.4 Optimal Feedback Control

An assumption of motor control is that several regions of the brain are activated during movement whereby any region can serve multiple purposes at any given time. In order to determine the temporal activation patterns of active regions the activation levels of the dorsal pre-motor cortex (dPM) and the 1M in non-human primates were compared by Crammond and Kalaska (1996). While both regions were active during the planning and movement stage, only the 1M demonstrated a high level of activity during maintenance of limb position. Therefore, while the 1M seems to be necessary for continuous movement execution, the dPM may play a different role during maintenance of posture. A leading theory of motor control postulates that cortical processes compare the actual motor plan to a reference copy, retained within the active processes in the brain during this cycle of movement-feedback (Todorov, Jordan 2002). It has been demonstrated that regions typically associated with sensory information are in fact activated prior to movement and are synchronized to activity in the dPM (Fromm, Evarts 1982). Figure 3 shows a schematic of the cerebral processes thought to be employed during the selection and execution of a voluntary movement.

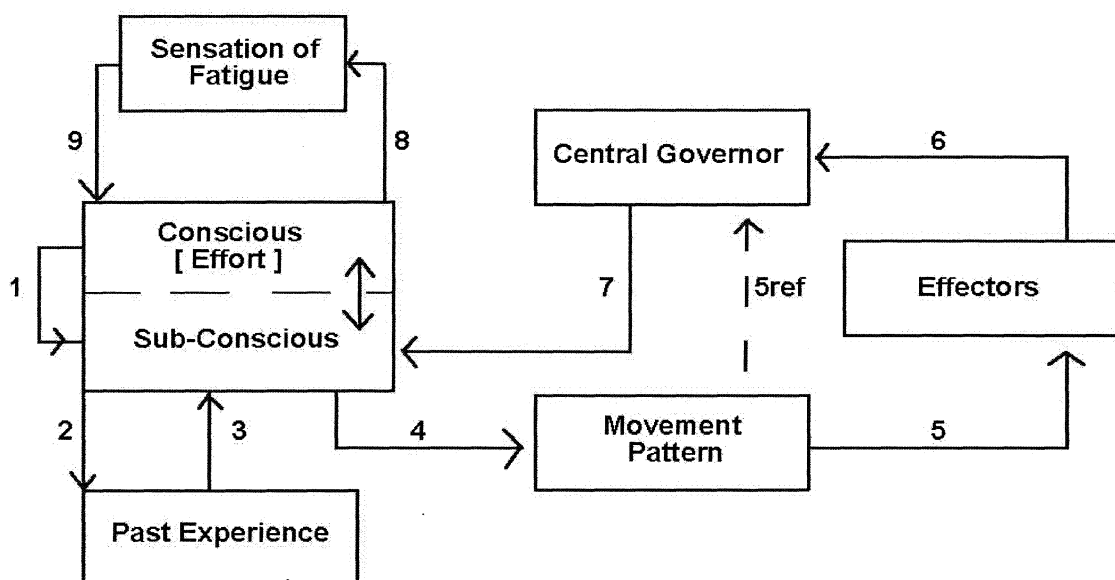


Figure 4. A Cerebral Schematic Outlining the Progression of Motor and Sensory Signal Transmissions during a Voluntary Movement.

5ref, reference copy of movement pattern. Numbers 1 – 9 refer to the direction of transmission. This process can occur anywhere without conscious initiation.

In addition, the results of Blakemore et al. (2001), who demonstrated that a reduced perception was associated with prior knowledge of touch, lend evidence to the feed-forward or anticipatory model of motor control. This model allows for (i) the outcome to be estimated before sensory information is available (ii) the efferent copy to be used to cancel out potentially debilitating sensory affects of movement (iii) comparisons between actual and intended outputs to allow for motor learning, and increases in movement efficiency, without movement, through mental imagery (Blakemore et al. 2001). This forward model theory has recently been advanced to exercise duration in performance settings. It is hypothesized that the continuous and conscious sensation of fatigue regulates the intensity based on the perceived exertion within the confines of a defined governor set by the subconscious (Noakes et al. 2001). The importance of this model is the unique approach to the quantification of fatigue, within this structure the sensation of fatigue is the limiter to exercise. In addition, pacing strategies are not simply a product of peripheral or central reductions in exercise capacity but rather can be further explained by anticipatory mechanisms (St Clair Gibson, Noakes 2004; Rauch et al. 2005).

2.5 Teleoanticipation

During self-paced events athletes collectively and consistently utilize a common pacing strategy (Abbiss, Laursen 2008; Tucker et al. 2006). Although a variety of pacing strategies are used depending on the event, during traditional laboratory aerobic exercise athletes prefer to select a consistently decreasing power output as a function of time (Abbiss, Laursen 2008), whereas during Ironman® triathlons participants display a non-linear strategy depending on direction of wind (Abbiss et al. 2006). In addition to muscle glycogen limiting

exercise capacity, Rauch et al. (2005) proposed that a chemoreceptor in the muscle quantifies glycogen concentrations before exercise to regulate initial energy expenditure. These findings lend support to the idea of an anticipated energy expenditure and corresponding strategy upon how to limit the onset of fatigue. When athletes exercise in a consistent and predictable environment their predictions of energy expenditure are more accurate and therefore the pacing strategy is more consistent, yet when competing in variable environments predictions are less accurate and non-linear models are more appropriate. The Central Governor model states that the CNS predetermines the magnitude for motor unit activation solely to maintain homeostasis throughout a task (Noakes 2007). Within this model pacing strategies are individually created by the brain, ensuring that perceived discomfort terminates exercise prior to loss of homeostasis (Noakes 2007). Athletes may perform with similar pacing strategies because they have trained to similar levels of fitness, therefore allowing a large number of them to anticipate the performance similarly and perform in a coordinated fashion.

The term RPE Clamp was recently defined by Tucker et al. (2006) to represent an effort that corresponded to consistent RPE (Borg Scale) maintained throughout the entire protocol independent of cadence, resistance, or external feedback (of which there was none). Work outputs set by various levels of perceived exertion demonstrate the ability of matching the metabolic rate to that of a subjective rating of intensity (Dunbar et al. 1992). The importance of teleoanticipation is the pre-determined selection of pace; in addition, it is matched with continuous maintenance of both biomechanical efficiency and metabolic rate such that exercise intensity does not exceed the limits of the body before an anticipated end point (Rauch et al. 2005; Ulmer 1996). In summary these findings suggest that the brain needs to be considered as a more complex structure than simply a reactionary organism as is predicated by the central and peripheral models for fatigue because it is in this manner that exercise is altered by the environment and controlled by the athlete.

Although mean power during self-paced protocols may display variable magnitudes (Rauch et al. 2005), it is thought that the apparently random instantaneous power output represents the complex system integration in which relevant physiological changes interact through different feed-forward and feedback systems (St Clair Gibson, Noakes 2004). Lucas et al. (2008) monitored the heart rate of 3 independent groups within an adventure race. Data was indirectly collected for both the first and last place teams and the results for all groups demonstrated a decline in mean heart rate for the initial 12 h, which stabilized throughout the rest of the event regardless of what the racers were doing. It remains unknown what caused the drop in heart rate after the first 12 h, but the authors speculate that a feed-forward feedback mechanism was at play (Lucas et al. 2008).

It has been argued that many of the current methods employed in exercise science limits the regulatory processes of the brain (Noakes et al. 2001). Currently much of the sport science research prescribes a steady work rate, eliminating the brains ability to regulate power output as a function of its current physiological status. Interpretations of data regarding exercise perception suggest that the 'sensation' of effort acts as an active regulator rather than a passive consequence of other processes (St Clair Gibson et al. 2001). Therefore, a new method allowing for central and anticipatory mechanisms to execute their homeostatic influences must be established. A reliable exercise protocol that is controlled by an individual's perception should lend support to the paradigm that the sensation of effort, rather than physiological parameters such as metabolic or respiratory fluctuations, is used to maintain physiological homeostasis. In order to find reliability it will be assumed that signals used to maintain homeostasis and predict a catastrophic end point will remain stable. What is still needed to be understood is how these sensory perceptions will affect the continuation of effort either individually or collectively. Nonetheless, while the use of differentiated RPE as an indicator tool is becoming more common, to date no clear understanding of the psycho-physiological regulation of our body in this simple environment exists.

2.6 Justification for Statistical Analysis

While a number of studies claim that perceived exertion is a reliable tool associated with specific exercise intensities Hopkins (2000) claims that only three studies (Buckley et al. 2000; Doherty et al. 2001; Lamb et al. 1999) took advantage of the more appropriate statistical quantification of test re-test reliability, the co-efficient of variation (CV) or Intra-class Correlation Co-efficient (R) in conjunction with limits of agreement (LOA). Disagreement plagues the results found in the 3 studies where CV and LOA were used. Lamb et al. (1999) had participants indicate their RPE during a graded exercise test and found it was not repeatable; it was also less reliable with increases in intensity. In contrast, Doherty et al. (2001) showed reliability for the perceived exertion during high intensity short term sprinting; specifically that a subject's perception of intensity was a reliable indicator of exercise during the first 2 min of constant load exercise. Ulmer (1996) noted that an adequate time needed for a reliable RPE can be as low as 1 min. While a transient RPE was found at the start of running, likely due to the short time frame of exercise and alterations in metabolic rates (Noble, Robertson 1996), reliability was found throughout a 2 min supra-maximal exercise (Doherty et al. 2001). The only study to assess the reliability of RPE as a product tool found reliability in Braille users when prescribing exercise intensity (Buckley et al. 2000). Although it is commonly accepted in the literature that local afferents dominate perceived exertion and are therefore most likely to contribute to the regulation of exercise (Ekblom Goldberg, 1971), the reliability for the maintenance of intensity using a product tool on a single muscle group has yet to be tested in an objective format.

Moreover, Weir (2005) stated that the use of the standard error of measurement in conjunction with R is the most applicable and statistically correct method to employ in reliability studies. The most common quantification of reliability in sports science the Pearson correlation coefficient (r), yet it has been questioned as a measure of reliability. The true use of r is a bi-variate analysis, relationship between two independent variables, and is not sufficient to determine reliability (Atkinson, Nevill 1998; Hopkins 2000).

2.6.1 Calculations

The statistical procedures presented will test for individual reliability within (LOA, R, SEM) subjects, each test will further determine the difference between the sexes of the individuals. Females have been documented to be more sensitive than males in terms of their perception and tolerance to pain, regardless of hormonal stage (Mitchell et al. 2004). Variance describes the distribution of the individual score in relation to the group mean. A Two-way (day x subjects) mixed model analysis of variance (ANOVA) may be used to assess the systematic bias between tests (Atkinson, Nevill 1998). The ANOVA will quantify the similarity of each repeated test for an individual and will be used to further calculate the R (Atkinson, Nevill 1998).

Pilot data was collected whereby participants performed indicator contractions on the days before and after 4 days of product exercise. The potential for a learning effect between trials is apparent when participants repeat the measure over and over and random order of tests is generally used by researchers to cancel out this effect. A learning effect was not seen in pilot data collected for the RPE during repeated indicator exercises ($n = 4$). While this is not directly related to the RPE Clamp it is useful to know that for a given torque output the perceived exertion is similar between before and after several trials.

As mentioned earlier Pearson's correlation coefficient (r) is not the most appropriate measure for reliability as it is unable to detect changes in the mean, and is a bivariate statistic that should not be incorrectly applied to univariate models (Weir 2005). A high correlation coefficient will be found if the data falls along any straight line, however not if the data shows agreement between sessions (Bland, Altman 1986). R may be used on multiple sets of data and is sensitive to changes in the mean between trials (Atkinson, Nevill 1998; Hopkins 2000). There are many R's that can be used with reliability studies. As R's are capable of detecting differences in test-retest and multiple repeated measures, both within and across subjects the choice of the appropriate R is very important. In brief, R is capable of determining the consistency of a result – whether a participant attains the highest score compared to all others on repeated days – or

the repeatability of the results – whether a participant attains the same score when measured against themselves. The use of consistency and repeatability are more commonly referred to as relative and absolute reliability respectively. Both Weir (2005), and McGraw and Young (1996) have provided excellent reviews on the choice and interpretation of this powerful statistic.

Another measure of absolute reliability is the LOA, an appropriate tool to measure the agreement between repeated measures as well as between measurement devices (Bland, Altman 1986). LOA is built on the assumption that the difference between attempts made by an individual does not increase as the magnitude of those scores increase. In statistics this phenomenon is called homoscedasticity. Interestingly, the measurements do not have to follow a normal distribution – only the difference scores must meet this requirement (Bland, Altman 1986). The advantage of the LOA over the previously mentioned statistical procedures is that it assumes a population of individual test-retest differences rather than an assumed population of repeated measures around a 'true value' (Atkinson, Nevill 1998). In brief, the LOA determines the upper and lower limits between which a new mean difference, from the population studied, should fall. The precision of such a measurement can be accounted for in a confidence interval (CI). The CI offers an estimate of the underlying pattern of population means and the statistical power of that pattern (Dunn, 2001). In relation to the LOA, the CI offers an indication of the precision of our limits, in other words how confident we are that the limit actually represents a real range that is not confounded by systematic error (Dunn, 2001). In brief, a wide confidence interval leads to the assumption of large variability within the data, either from a small sample size and/or large variation in the differences between repeated trials. A small CI can be assumed to be the opposite, and is usually if not always preferred in clinical and scientific research. Absolute reliability can also be measured from the SEM (Hopkins 2000). Such a measure gives an indication of random variance in an individual's value when tested multiple times (Hopkins 2000). Unfortunately, this random variation includes biological, technical and systematic sources that are unavoidably lumped together (Hopkins

2000). As an advantage, the SEM is largely independent of the population used to determine the value and can therefore be used to assess reliability across difference samples (Weir 2005). Determination of the SEM allows for the estimation of a subjects true score, the score that a subject would attain if no variance was present. This minimum difference (MD) is used to define a range where a subject's true score will lie, and any score outside this range is considered statistically different (Weir 2005). The use of these 3 tests will create a multidimensional picture on the reliability of an isometric test based on the perceived exertion.

3 Chapter 3: Purpose and Hypothesis

3.1 Purpose

1. The purpose of this project is to determine the reliability of a protocol to reproduce similar sub-maximal isometric contractions without external feedback (i.e. torque, time left).
2. If reliable, this design will allow for the investigation of self-paced work intensity in a variety of altered environments – oxygen content, barometric pressure, temperature and more. It will also permit the potential extrapolation of this concept for a wider variety of exercise modalities including isokinetic, and whole body exercises.

3.2 Hypothesis

1. Based on the qualitative finding from Cain and Stevens (1971) our null hypothesis states that the individual perceived exertion will create a similar isometric torque between successive days.

4 Chapter 4: Methods

4.1 *Participants*

Twenty-two healthy and active male ($n = 9$) and female ($n = 13$) high performance university athletes were recruited for their increased muscular coordination attained through regular muscular training. All participants were fully informed of the details of the study and all associated risks, and willingly signed informed consent prior to any data collection. The research ethics board at Brock University approved the study (**REB – 08-046**) prior to any participants being contacted. Participant selection included athletes who participate in events with sustained isometric and intermittent contractions; examples of which include wrestling, rugby, ballet, and cycling. Varsity athletes were chosen when available. As only 17 varsity athletes were available, a more open selection was undertaken and included highly active participants. Highly active was operationally defined as exercising for a minimum of 1 h per day, 4 d per week with at least 2 h per week spent weight training. All participants were asked to maintain their regular levels of training but to abstain from any extra heavy physical training for the week of data collection (further referred to as exercise). Subjects recounted the previous days exercise at the start of all data collection sessions. A similar approach was taken for caffeine ingestion where all participants were asked to maintain a regular caffeine diet but to abstain from caffeine for at least 2 h prior to data collection. It was demonstrated that caffeine attenuates force sensation when measured one hour after ingestion (Plaskett, Cafarelli 2001). Exercise and/or caffeine ingestion was not altered to a large extent; we speculated that changing such variables for an entire week would have too large an impact on the individual's perception and emotion of events. Furthermore, all participants refrained from alcohol throughout the week.

4.2 *Equipment Set-up*

All muscular contractions were performed on a BIODEX (Biodex Medical Systems, Fremont CA) using the participant's dominant leg, defined as the

preferred leg used for kicking. During all contractions subjects sat in an upright position with the hips and knee at an angle of 90° . The participant's anatomical position (0°) is used as reference for all angles. Joint angles were set by the investigator as determined by a goniometer. The leg attachment was strapped immediately proximal to the condyles of the lower leg. Furthermore, the lever arm for the BIODEX was measured and recorded in an effort to replicate the exact set-up between trials. The joint centre of the knee was placed at the centre of rotation of the mechanical lever arm attached to the BIODEX. Inertial properties of the lower leg were quantified using the software provided (System 3, Fremont CA) where further analyses was altered to minimize the effect of leg weight. For all contractions each subject's movement was constrained with the use of Velcro straps placed across the waist, each shoulder, and active thigh, while their arms were folded across the chest.

4.3 Familiarization

In addition to muscular activity several subjective measurements including Borg's (1982) rating of perceived exertion (15 point category scale), and a 100 point self-efficacy scale were utilized before and after the activity. Furthermore, blood pressure was measured preceding and following each contraction. The familiarization process allowed the researchers to completely explain the basis of each measurement and allow for participants to experience all aspects under investigation. In addition, the same investigator was present for all data collection, and was responsible for maintenance of the set-up and data collection.

Self-efficacy (SE) is defined as the belief in one's capability to perform a required action and generate the specific outcomes that are expected of a certain situation (Duda 1998). Prior to the relevant exercise and type of contraction on the particular day, participants orally answered questions based on their self-efficacy. This quantified their level of confidence for either the indicator or product exercises. Questions were constructed around 3 separate timeframes, 0 – 30s, 30 – 90s, and 90 – 120s. These times were chosen as they represented typical

points of fluctuation in the level of effort during pilot testing. All questions were read aloud and participants were asked to rate their SE using a scale that ranged between 0 and 100. Questions were asked in the following manner “on a scale ranging between 0 and 100, with 0 reflecting an absolute lack of confidence and 100 reflecting pure confidence, please rate self efficacy in your ability to maintain a steady perceived exertion for 30 s.” Following all data collection, a scale of identical structure quantified the subject’s perception of how well they were able to maintain their torque during the product exercises. Questions were structured to determine the participant’s ability to distinguish the relative differences between perception and actual output.

During the remainder of the visit all subjects underwent an extensive familiarization session on the BIODEX. The primary focus was to have participants perform at least 3 x 4 s maximal voluntary contractions (MVC), practice sustaining sub-maximal contractions for up to 120 s, and become familiar with the RPE scale, SE measurements and BP readings. A complete dry-run of the protocol to be used on day 1 (explanation to follow) took place. The primary investigator set subjective boundaries for the RPE scale using both numerical, verbal, and exercise cues (Gearhart et al. 2004). Memory anchoring involved an explanation of the sensation at both the minimal and maximal effort levels in the absence of physical work. On the other hand, exercise anchoring utilizes a task specific exercise whereby anchors are explained during minimal and maximal exercise. This combination of anchoring has been found to be highly valid during cycling exercises (Gearhart et al. 2004). While lying in a reclined position on the BIODEX chair, participants were instructed that the rating of 6 is not unlike lying in bed or sitting in a chair. Following the repositioning of the chair to an upright position subjects performed a maximal contraction and were informed that a maximal rating on the RPE scale was synonymous with giving an all out effort. In addition, subjects were verbally reminded to focus on the perception of the muscular effort during the subsequent indicator exercise. It was assumed that the small increments in effort afforded the participants the ability to gauge changes in perception of intensity (Gearhart et al. 2004). BP

readings were taken using a sphygmamometer immediately preceding and succeeding muscular contractions. Subjects were positioned in the chair while a cuff was placed around the subject's right arm. Following the contraction the cuff was re-inflated and a second reading was recorded before straps were removed or loosened. BP was further processed into mean arterial pressure (MAP). All subjects were confident in each procedure prior to leaving the familiarization session. Furthermore, participants had free access to retry any procedure.

The learning effect associated with a MVC has been shown to be minimized with a single extensive familiarization session (Colombo et al. 2000; Morton et al. 2005; Thepaut-Mathieu et al. 1988). While no difference was found between sexes in the ratings of perceived exertion, a low reliability of the knee flexors to produce both a similar perceived exertion and MVC on a single test retest model was found (Pincivero et al. 2003). A straight interpretation of this data cannot necessarily be made to the presently proposed methodology. Only 10 subjects were used – a very small representation of the population for a reliability study – and all contractions were maximal, as well the potential factor that knee extension may be a more reliable muscle group due to its increased need for primary coordination in many recreational activities (kicking a ball, leg raises, squats, jumping etc).

4.4 Experimental Design

Within 3 days of the familiarization subjects underwent 4 successive days of muscular testing for the quantification of isometric contractions as controlled by their RPE. Day 1 consisted of a MVC, a single indicator and product exercise. Day 2 and 3 consisted of a quick reminder of the purpose followed by a single product exercise. Day 4 was a mirror opposite of day 1; it included a product, indicator and maximal contraction in that order with identical breaks to day 1. This design allowed for the determination of 4 successive product exercises.

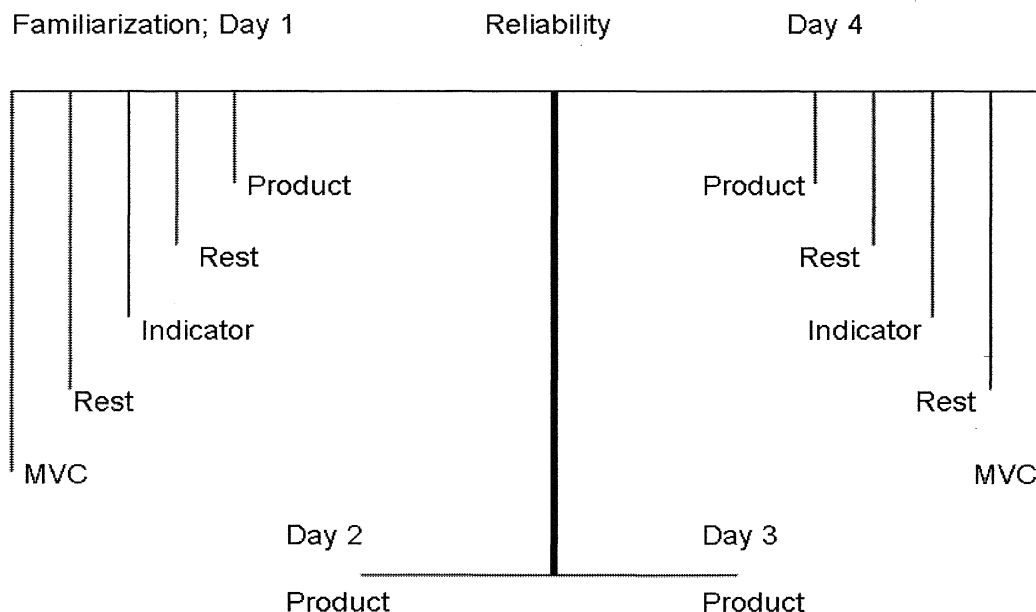


Figure 5. Overview of the Experimental Design. Rest, 30 min; Reliability, testing of Product Exercise.

4.4.1 Maximal Voluntary Contractions

Subjects underwent 3 attempts at a maximal voluntary knee extension. Contractions were held for 4 s with a minimum of 2 min rest between successive contractions. The duration of 4 s has shown to produce reliable results across multiple days (Morton et al. 2005). During the rest all participants remained seated in the BIODEX and straps were loosened to promote blood flow. Maximal values were only accepted when the torques produced fell within a 5% difference between contractions. The mean of the 3 attempts was calculated and utilized for further analyses. The practice of anchoring each participants RPE to basal and maximal levels was done prior to and immediately following the MVC (Gearhart et al. 2004). This involves the process of associating a minimal and maximal effort with sitting and MVC, respectively.

4.4.2 Indicator Exercise

Following the collection of MVC subjects rested for 30 min. During the rest all straps were removed and subjects were encouraged to spend at least 5 min walking at a light pace prior to sitting down in a computer chair until further testing was initiated. Following the 30 min hiatus subjects were instructed to perform the indicator exercise. All participants were again seated in the BIODEX and all necessary precautions from the MVC were repeated. Prior to the contraction SE and BP measurements were made. For this contraction participants maintained a sub-maximal contraction that was set at 30% of their respective MVC for 2 min. They were provided with visual feedback from a computer monitor that displayed a bar graph which instantaneously depicted the torque generated around the joint centre. Subjects were instructed to focus on maintaining the bar graph to the calculated percentage of MVC for the entire duration. Throughout the exercise a differentiated rating of perceived exertion was collected every 30 s. For the collection of RPE, a scale was taped alongside the bar graph in a position that minimized the effect of altered concentration. Following their quantification of exercise intensity the researcher reminded the participant to concentrate on the feeling that was associated directly with the quadriceps muscles. Following the contraction BP measurements were repeated.

4.4.3 Product Exercise – RPE Clamp

All subjects received an identical 30 min rest following the previous activity. The mean RPE obtained from the indicator exercise was calculated and used to control the perceived exertion throughout the product exercise. In the situation where the RPE was averaged at a near maximal level (>16), the product exercise was set to 16. In cases where the range of RPE throughout the indicator activity was larger than 5, only the values within the range of 5 were used in the calculation for the RPE Clamp.

During the rest period subjects were reminded of the definition of the RPE Clamp and all visual feedback was removed. Straps and tension were reset and the leg was tightly secured at the proper angle of 90° for contraction. BP and SE

were made immediately after participants were placed in the chair and before the contraction. For the RPE Clamp, subjects were instructed to reproduce the prior muscular contraction intensity based directly on their perception of the effort. A warning from the test administrator happened just prior to a beep from the data collection system; this marked the start of muscular contraction and the commencement of data collection. Subjects then performed a 2 min contraction at their mean RPE from the indicator exercise. All external feedback, except for the collection of each individual's RPE, was removed from each product trial.

4.5 Statistical Analysis

Predictive statistical software (SPSS 16.0, Chicago Illinois) and Microsoft excel (Office 11.0) was used to address all statistical procedures. The variable of sex was controlled for by matching men and women with similar fitness levels/training and age. Using excel, a student's t-test compared the difference between the average of three maximal contractions from day 1 and the 3 maximal contractions from day 4. SE and BP were not measured with the MVC.

A student's t-test was used to determine the difference in average torque generated during the indicator exercise on day 1 & 4. Average torque was defined as the statistical average of all data points during the entire 2 min contraction. In addition a 2-way (day x subject) analysis of variance (ANOVA) was used to test for differences between the measures of SE that were collected prior to each indicator exercise. The same statistical procedure was done for MAP across all 4 days of contraction.

Torque reliability was evaluated according to R, Limits of Agreement (LOA), and the standard error of measurement (SEM). As the group was quite heterogeneous no smaller groups were apparent based on training or other factors therefore all data were analyzed together. Using mean torque from the product exercise, a 2-way (day x subject) mixed effect model of intra-class correlation coefficient (ICC (A,1)) tested for absolute reliability (McGraw, Wong 1996). Again, mean torque was defined as the statistical average of torque generated over the 2 min contraction. Following calculation of the ANOVA, the

mean square error term between rows (MS_R), mean square error term between columns (MS_C) and mean square error (MS_E) are used to calculate the variance term or reliability – formula seen below (McGraw, Wong 1996).

$$\frac{MS_R - MS_E}{MS_R + (k-1)MS_E + k(n-1)(MS_C - MS_E)}$$

Following this procedure, the LOA tested the difference scores to determine absolute reliability (Atkinson, Nevill 1998; Bland, Altman 1986). Here difference scores between successive days were plotted against their mean value (Atkinson, Nevill 1998; Bland, Altman 1986). Average torque for each subject was assessed between day 1 & 2, 2 & 3, and 3 & 4. This technique allows for a visual representation of measurement error and true value, estimated by the mean of the 2 scores (Bland, Altman 1986). To determine the precision of the LOA, both standard errors and 95% confidence intervals (CI) were calculated. A detailed explanation on the calculations for the LOA, standard errors and CI's are presented in Bland and Altman (1986). In addition to the absolute reliability determined with LOA, the SEM was calculated as it contains useful applications to data interpretation and is intimately connected to the R (Weir 2005). This value considers both the difference due to fluctuations in the experimental procedure and the difference accounted for by measurement error (Weir 2005). To avoid the influence of systematic error on the determination of the SEM, it can be estimated by calculating the square root of the mean square error (MS_E) term (Weir 2005). Therefore, it is calculated independent of the ICC and offers a measure capable of comparison across studies (Weir 2005). Application of the SEM defines the difference needed between separate measurements in order for that difference to be considered real, this is further termed the minimum difference or MD: $MD = SEM \cdot 1.96 \cdot \sqrt{2}$ (Weir 2005). Further work using a constant effort contraction can statistically show a difference, with 95% confidence, if their measured score is greater than the MD attained in previous reliability studies. In addition to the reliability calculations, a 2-way (day x subject) analysis of variance (ANOVA) was used to test for differences between the measures of SE and for the measures of BP measured during the product exercises.

Chapter 5: Results

4.6 Data Screening

Prior to performing any analysis all data were screened for outliers and were evaluated for the assumptions of normality, heteroscedasticity and singularity. Exclusion criteria for minimal exercise prior to testing sessions required the removal of one trial in the data set. Prior to data collection on day 3 for subject 17 the individual had taken part in a 1 h high intensity cycling class. The data sample was found to follow a normal distribution, as defined by Corty (2007). Within this definition the 95% confidence interval (95%CI) for both the skewness (0.89) and kurtosis (-0.51) must contain the value of 0. Heteroscedasticity is defined as increases in the difference scores paired with increases in the mean value and was analyzed with a Bland-Altman plot. Heteroscedasticity was found with the data. When the difference score is related to the mean in this way the LOA will be wider apart for small differences and narrower for large differences (Bland, Altman 1986). Logarithmic transformation of the raw data prior to and antilogarithm transformations after manipulation allow for simple and direct comparisons while correcting for heteroscedasticity (Bland, Altman 1986; Bland, Altman 1999). Singularity was not found within the data as determined by SPSS (Version 16.0). Furthermore, it should be noted that 3 subjects had previous experience with the RPE Clamp protocol in a whole body setting, however every subject was naïve to the isometric protocol utilized in this study.

4.7 Maximal Voluntary Contraction and Indicator Exercises

All data are presented mean \pm standard deviation; significance was set at a probability of 0.05 unless otherwise stated. Torque generated during the MVC on day 1 (230.43 ± 92.24 Nm) was significantly greater than on day 4 (218.35 ± 92.83 Nm). In addition, 18 subjects had an averaged MVC that was lower on the last day.

The magnitude of force that was required during the indicator exercise was relative to each participants initial MVC. Mean perceived exertion during the indicator exercise was significantly less on day 1 (16.98 ± 2.24) than on day 4 (17.52 ± 1.88). Data for MAP and SE was collapsed across all 4 days and between sexes as no difference was found. MAP significantly increased from 81.72 ± 17.12 mmHg to 89.6 ± 7.09 mmHg during the constant force contraction. Participants SE – to maintain the desired force – significantly decreased between each measurement from 98.08 ± 4.62 to 90.74 ± 11.23 , and to 83.74 ± 18.33 for 30, to 90 and 120 s respectively.

4.8 Product Exercise

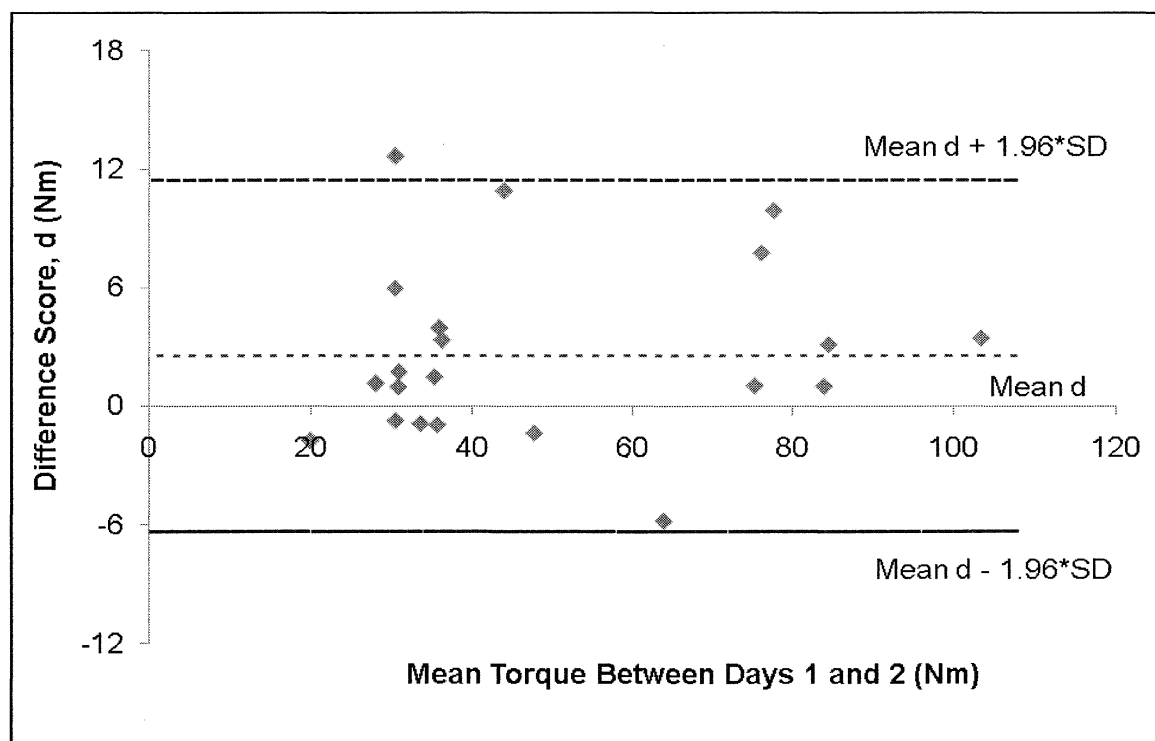
Reliability calculations were analyzed (i) on a day to day basis for the LOA, and (ii) in one complete data set for the R and SEM. This was done to reflect the eventual use of the product exercise as a dependent variable used on a day to day basis while retaining a statistical measure for overall reliability. Table 1 displays the results for the limits of agreement of each test as well as the 95%CI for each day. Limits between day 1 and 2 demonstrated a moderate reliability with the second trial ranging anywhere from 6.34 Nm below to 11.44 Nm above the first. The 95% CI for the difference score provided a small range for each day, its value was calculated to be ± 2.55 Nm between days 1 and 2, to ± 2.105 Nm between days 3 and 4.

		95% CI (Nm)							
Days	Difference (Nm)	LOA	LOA	95%CI (Nm)		Lower Limit		Upper Limit	
		Lower (Nm)	Upper (Nm)	From	To	From	To	From	To
1 - 2	2.55	-6.34	11.44	0.49	4.61	-9.90	-2.77	7.87	15.00
2 - 3	0.12	-9.63	9.87	-2.14	2.38	-13.54	-5.72	5.96	13.78
3 - 4	-2.10	-8.47	4.27	-3.58	-0.63	-11.03	-5.92	1.71	6.82

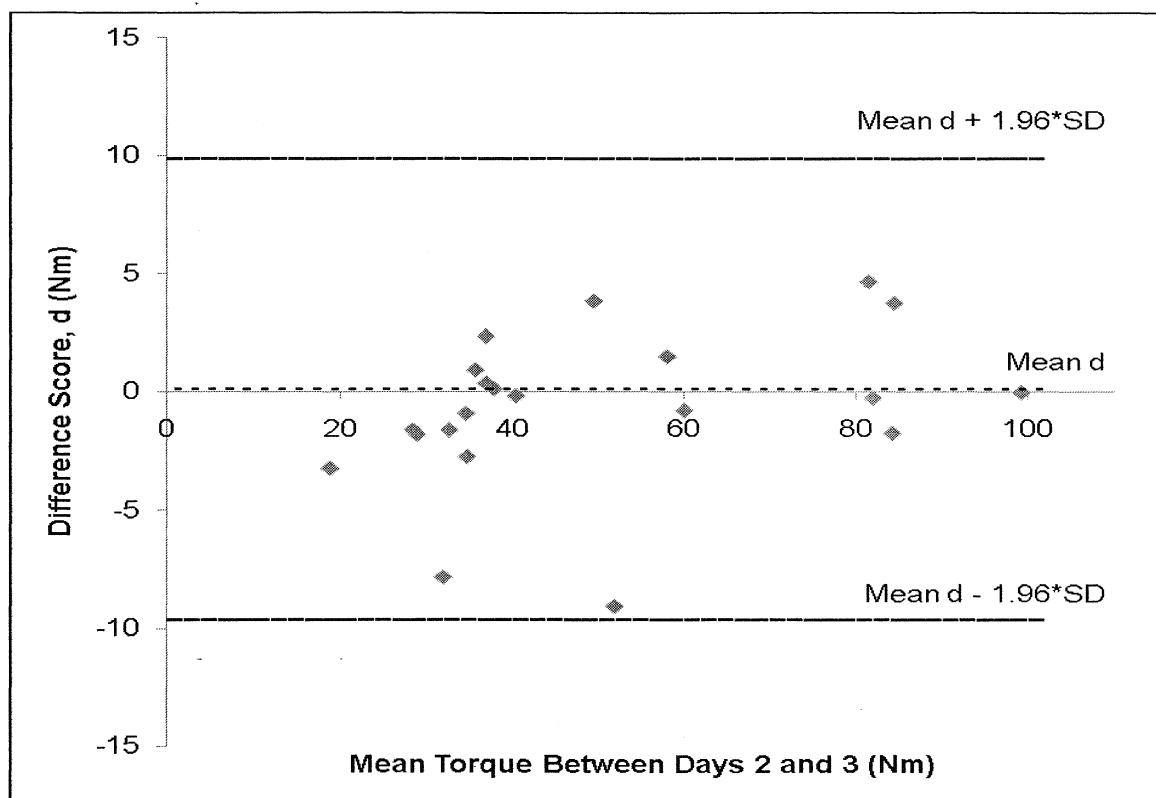
Table 1. Limits of Agreement for the Product Exercise

Furthermore, this relationship demonstrated improved agreement with successive days (Table 1; Figure 4). The mean square error for the product exercise was used to estimate the second measure of absolute reliability. The product exercise had an SEM of 5.12 Nm. Following the definition from Weir (2005) our minimum difference (MD) was 14.17 Nm. The Intraclass correlation coefficient demonstrated a strong reliability for the 4 consecutive product exercises ($R = 0.949$). Relative change in mean torque between successive days is shown in Figure 5. The majority of the differences were less than ± 10 Nm from the previous day.

(i)



(ii)



(iii)

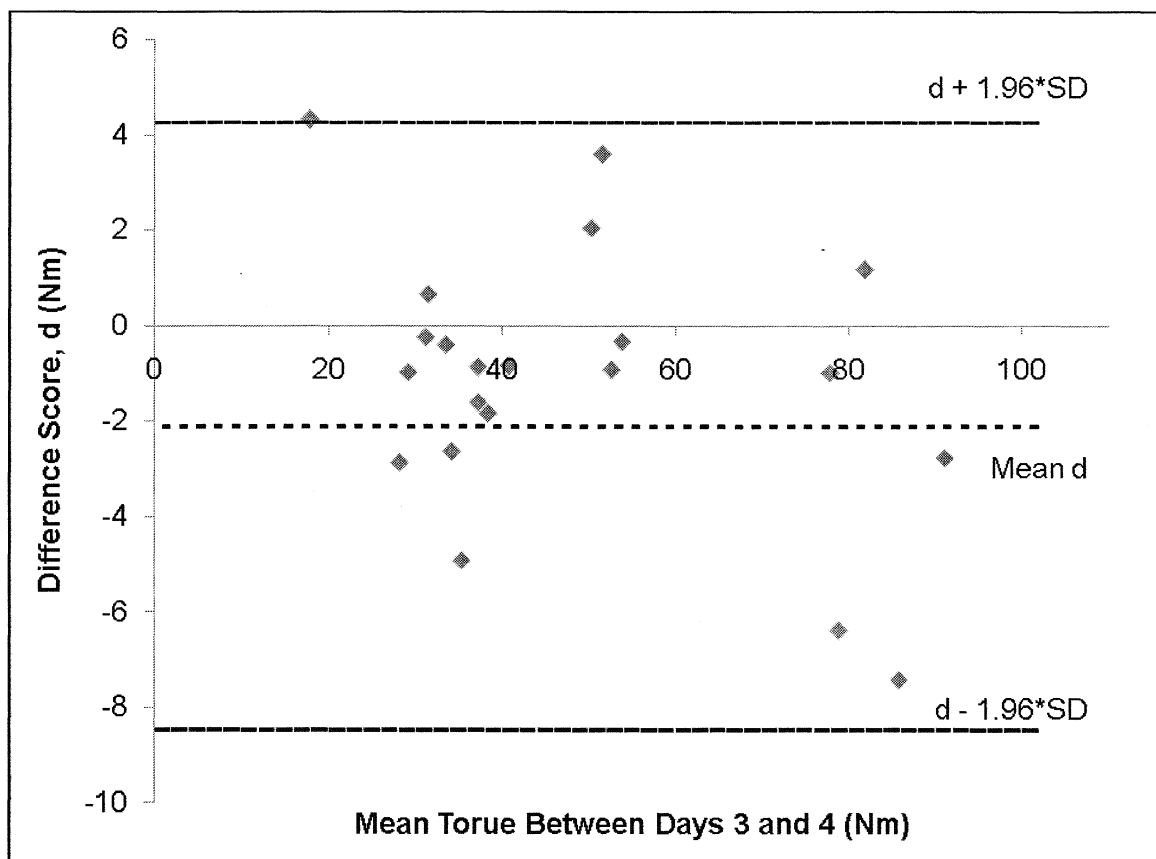


Figure 6. Bland Altman Plots and LOA for the Product Exercise

(i) day 2 – day 1 (ii) day 3 – day 2 (iii) day 4 – day 3; – – – upper and lower limits of agreement; - - - The average difference score between days and across all subjects; d, difference score; SD, standard deviation

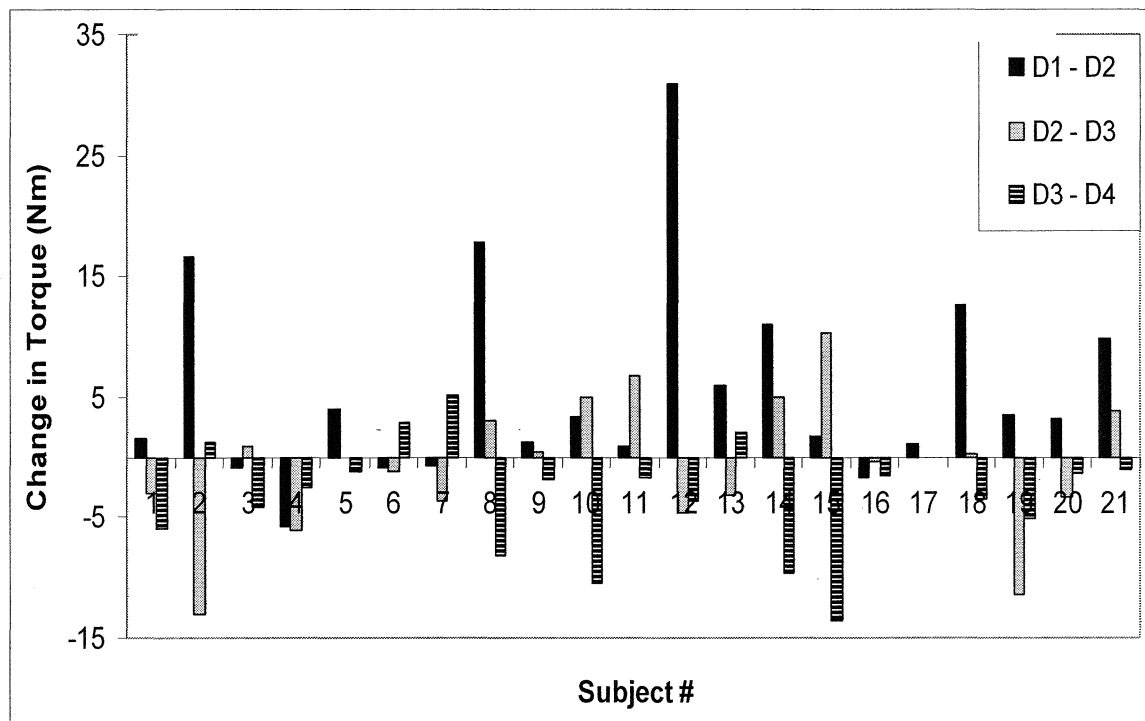


Figure 7. Relative Change in Torque between Successive Days of a Constant Effort Contraction

A qualitative analysis of the force-time profiles was made the primary researcher and several naïve individuals. Within this analysis the pattern of force reduction during the product exercise was compared across all subjects; a within subject analysis was not employed because each participant displayed a consistent pattern within themselves. In order for comparisons to be made across the range of strength that was present in our sample, all data was normalized to each person's respective MVC. The groupings were then averaged out into separate patterns. Figure 6 displays the results from these groupings where the changes in force are classified into 2 distinct patterns: linear (n=17) and negative (n=4). Linear patterns tended to display a continuous reduction that maintained a consistent slope throughout the duration of the contraction. In other words no

asymptote was found on the pattern of forces; it was therefore speculated that these participants would either continue on in this manner or reach an asymptote only with a longer/more intense contraction. Negative patterns tended to display a sharp initial reduction followed by the maintenance of force after the first 20 – 30 s. This group was thought to show an ability to maintain this force for a long duration; their data approached an asymptote towards the latter half. No relationship existed between initial torque and force pattern. All subjects in each group demonstrated a large range of initial torques.

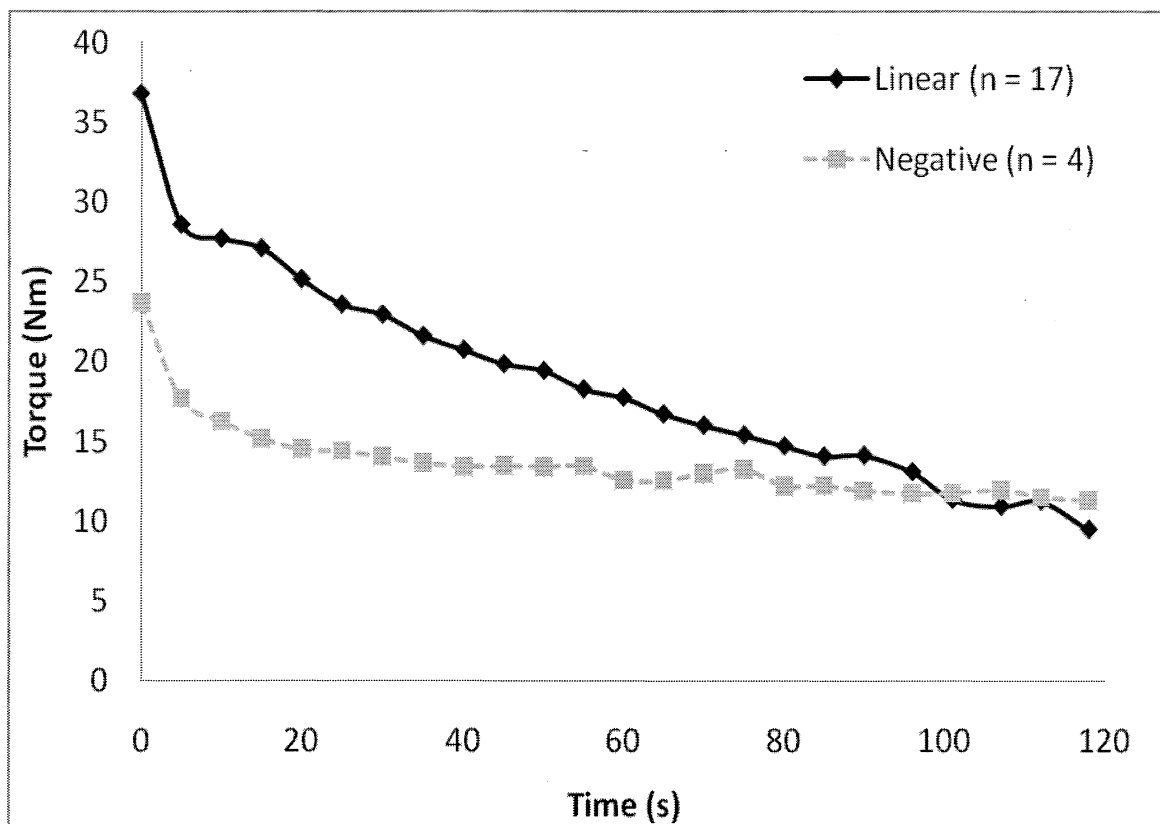


Figure 8. Pattern of the Force Profiles across Individuals during the Constant Effort Contraction.

Comparison of actual and perceived torques during the constant effort contractions demonstrated that subjects overestimated the amount of torque generated throughout the contraction (Figure. 9). Moreover, subjects consistently produced less force during the product exercise when compared to the indicator

(48.37 ± 22.6 Nm versus 66.15 ± 25.99 Nm respectively). All participants held the product exercise at an RPE rating of either 15 or 16.

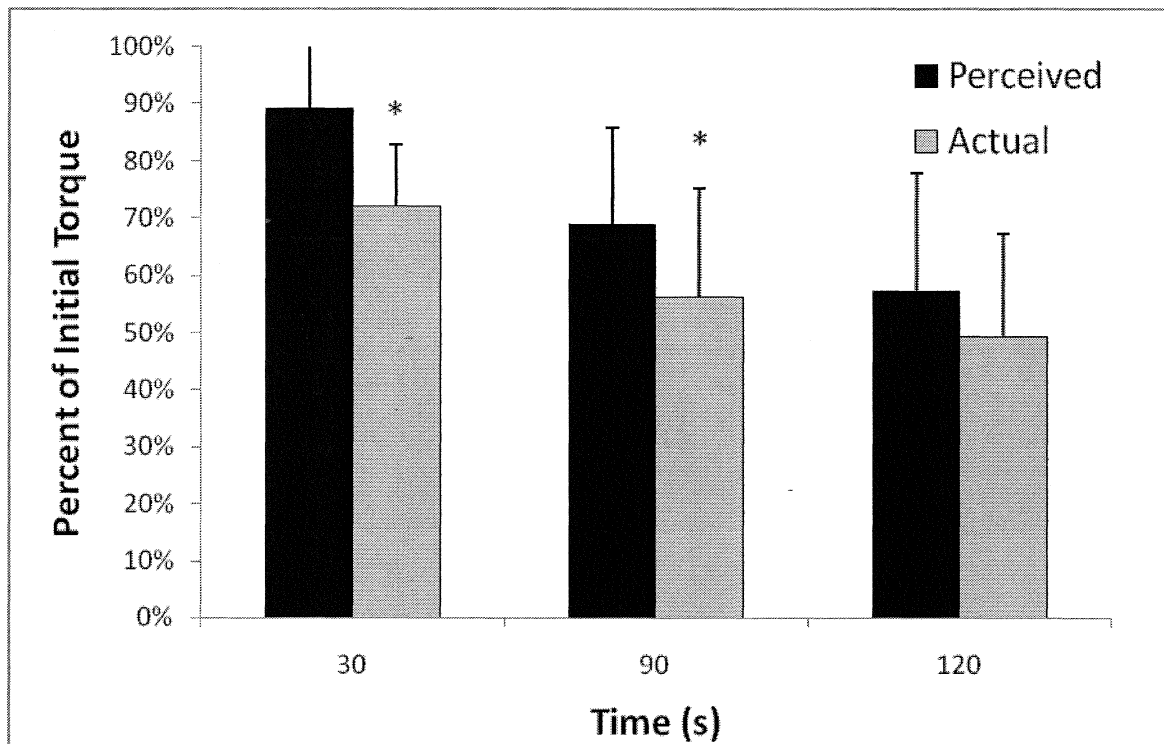


Figure 9. Comparison of Actual and Perceived Torque during a Product Isometric Contraction.* Denotes statistical difference from perceived torque at that time point

No significant differences were seen between days for any of the MAP or SE measures, therefore data were collapsed across days and sexes. MAP significantly increased during execution of the product exercise (85.3 ± 39.0 mmHg to 90.6 ± 42.9 mmHg, $p < 0.01$). A Two-way RM ANOVA revealed a decreasing SE between each time period $97.0 \pm 5.6\%$, $94.18 \pm 9.3\%$ and $91.45 \pm 12.14\%$ at 30, 90 to 120 s respectively (Figure 10).

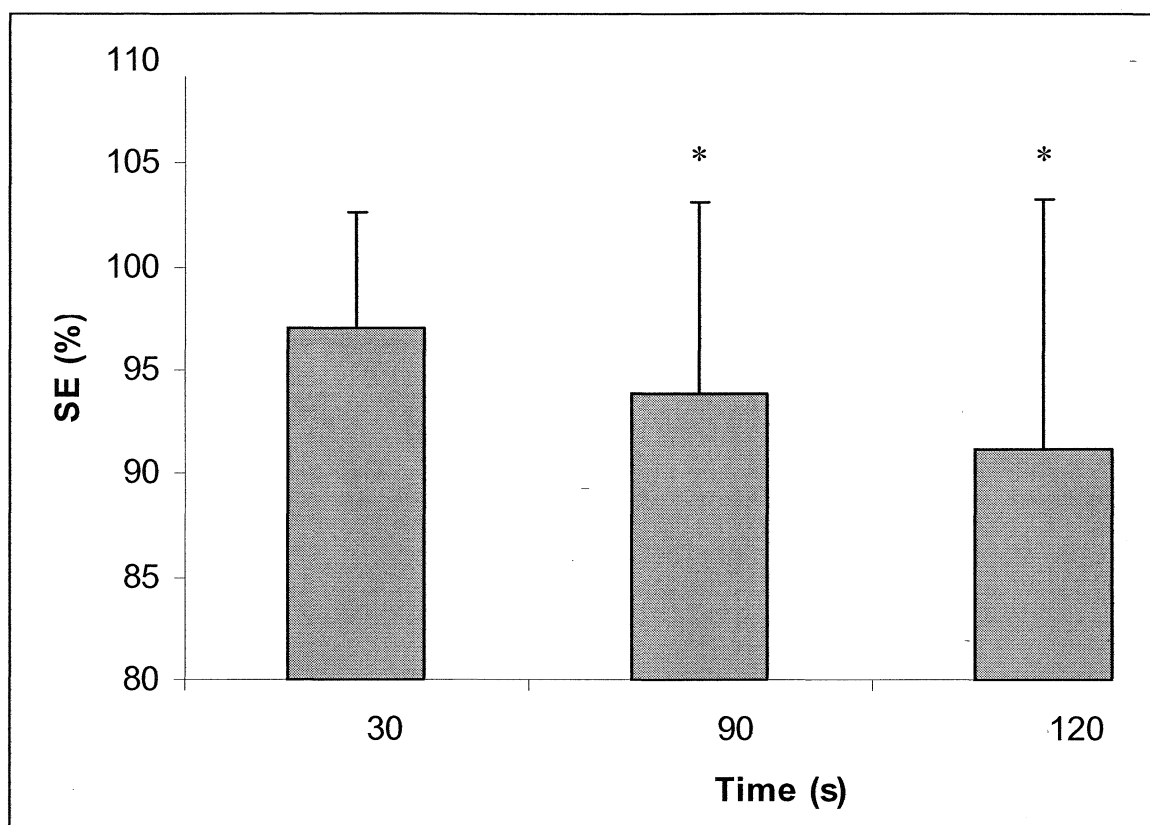


Figure 10. Self Efficacy Prior to a Constant Perceived Effort Isometric Contraction. Comparison of the averaged Self Efficacy at the 30, 90, and 120 s mark across four days of product exercise contractions. * denotes statistically significant differences from 30 s.

5 Chapter 6: Discussion

5.1 Summary

We observed that the capacity of a product exercise to regulate a consistent muscular output – as measured by average torque – within an individual is a reliable approach; however precaution must be taken as several of the statistical measures demonstrated a lack of reliability in certain respects. Absolute agreement as assessed by the R demonstrated an excellent reliability ($R = 0.949$). Given the results of the LOA, our samples reliability may be slightly susceptible to trainable factors and is susceptible to a wider range of day to day variability with 3 or 4 familiarization sessions. The force pattern generated during a sustained constant effort isometric contraction tends to be highly consistent within an individual; however when comparing across individuals 2 patterns exist (linear or negative). A significant difference exists between the subject's perception of force and the actual amount produced during the constant effort contraction. While not directly measured, we speculate that the mechanism responsible for the training effect of reliability is an increased association between perceived and actual force.

5.2 Reliability of the Constant Effort Contraction

Three distinct measures were used to assess the reliability of our protocol. All measures determined absolute reliability; yet all measures were unable to demonstrate consistency. R (0.949) and the SEM (5.12 Nm) determined high absolute reliability when assessing the test in an overall manner. The R is one of the most popular methods to assess the reliability of repeated measures, but may become inflated when assessing values that are spread out over a large range. Nonetheless it is supported as an acceptable measure of reliability providing it is not the sole value reported (Atkinson, Nevill 1998). Hopkins (2000) defines the SEM as the variation that we would expect to see from trial to trial if any one of these participants performed multiple trials. As is seen in the data

presented with this work both of these measures demonstrate high reliability. Other measures that were calculated with our sample tended to show less reliability. Interpretation of the SEM was extended to the practical measure of MD, which shows that a difference of 14.17 Nm is needed to attain a statistical significance in future studies (Weir 2005). The LOA demonstrated moderate agreement between consecutive days of testing. Using a 95% CI, repeated trials may be anywhere from 13.54 Nm below or 15 Nm above previous days. When assessing the data on a day to day basis, the LOA indicate that subjects performed with less variability towards the end of the week. The relationship between the measures found from these statistics is not easily interpreted into a single reliability answer. The results lend themselves to the idea that an athletic population is capable of producing consistent muscular outputs when controlled by a constant perceived exertion providing sufficient training is provided. In addition, the absolute reliability of an individual only partly resembles that of Cain and Stevens (1971). Here subjects were cued to a specific absolute force and asked to maintain the perceived exertion for 2.5 min. Although they never statistically addressed reliability they found that subjects performed in the same manner across repeated trials. Using the results of the current protocol and analysis to speculate it seems as though athletes trained in a specific muscular action are able to draw on previous experience and produce similar muscular outputs based only on a constant perceived exertion.

5.3 Force Production during the Product Exercise

Two unique force profiles for a constant effort, isometric leg extension were documented. The pattern of one subject demonstrated an increasing torque for every trial. Consequently their data was not used in this portion of the data analysis, yet their data was kept for all other measures including reliability analysis. This particular individual has participated in a constant effort cycling protocol that was previously used in our laboratory. Interestingly the power that was generated during the cycling trial followed the same pattern; yet within our laboratory no other participant has ever demonstrated this pattern in either

isometric or whole body exercise. As this subject had previous experience with the RPE Clamp protocol in a whole body setting it was not assumed that the change in force was due to a misunderstanding in the protocol. We can present no information as to why the force or power increased. A comment from the subject after all data was collected revealed the following “as time went on I could deal with the burn, so I pushed harder to maintain the effort”.

In regards to the patterns found for the force profiles, it is assumed that a difference in perceived exertion originating from alterations in neural (Plaskett, Cafarelli 2001) or local factors (Ekblom, Goldberg 1971) may be responsible for generating their pattern. The negative pattern ($n=4$) was characterized by a similar decay as that previously documented in isometric contractions (Eason, 1959; Cain, Stevens 1971; Cain, Stevens 1973; Abraham, Craig 1975; Jones, Hunter 1983). These previous results demonstrate a potential asymptote or indefinitely maintainable level of force output. If these participants had a lower pain threshold their muscles may have required a large reduction in force from the start in order to maintain the perceived exertion, thus creating the fast initial loss in muscular force. Previous work has speculated that this rapid decrease in muscular force is a function of processes external to the muscle itself. After the initial reduction in torque the lower muscular force may not have been substantial enough to elicit a change in perception, and thus muscular force was able to be maintained. Participants asked to maintain 15% of their MVC in a constant effort contraction, demonstrated maintenance of their force at a much more consistent level when compared to 30% MVC (Abraham et al. 1975).

In contrast to all previously published data, our most typical result demonstrates a consistent and continual reduction of force with time, which is further extrapolated to reach a force level of zero. If these subjects had a higher pain threshold they may have been able to maintain an increased torque for a longer period of time. In regards to the pattern, it is assumed that these participants held a higher torque and potentially slowed blood flow more than subjects who followed a normal pattern. Cain and Stevens (1971) allude to their unpublished data regarding the fact that when participants underwent constant

effort contractions under blood occlusion a consistent reduction in force was seen.

In all previous constant effort contractions the subjects have been cued to the magnitude of force they were to maintain prior to removal of feedback, and were aware of trial duration. In our study individuals started with a resting muscle and were required to increase muscular activity to match a previous RPE. As such, all participants were only aware of trial duration and had no external feedback – except the acquisition of their RPE – throughout the entire trial. The addition of memory related processes in combination with a short duration and high intensity of effort may have drastically impacted reliability. Other results have demonstrated that power decreases shortly after the start of exercise during cycling in different environmental conditions, suggesting that performance is altered in advance of catastrophic events (Tucker et al. 2006). While no time frame was reported for the change in power, rate of heat storage during cycling in the heat was found to be greater for only the initial 4 min when compared to normal and cool environments (Tucker et al. 2006). Therefore, if the change in heat storage was due to the reduced energy expenditure, the mechanisms of anticipatory processes must have established their effects within this timeframe. In addition, constant effort results for running, swimming and cycling demonstrated continuous decreases in velocity during high intensity efforts and plateaus of velocity during low intensity efforts (Ulmer 1996). We speculate that a lower product exercise may be necessary for isometric contractions in an effort to maximize the potential for a feedback process to significantly alter neuromuscular output. Unfortunately, direct comparisons across previous literature are not possible because perceived exertion has previously been measured with different scales or was predetermined as in Cain and Stevens (1971). The use of an independent measure, SEM, in reliability studies is therefore appropriate as it will allow direct comparisons.

Results from constant force isometric contractions have revealed that the decrease in force is not primarily due to fatigue (Cain, Stevens 1971; Cain, Stevens 1973; Abraham, Craig 1975). Instead, the leading paradigm proposes

that central output to the alpha motor neurons is decreased via feedback from the Golgi-tendon organs (GTO). In such a model the inhibitory stimulus, originating with the GTO, is increased when the higher order sensory cues are removed. For example, visual properties are unable to detect the decrease in force; in turn they do not stimulate the appropriate higher cerebral processes responsible for alpha motor neuron stimulation (Abraham, Craig 1975). While this accounts for the rapid initial response, ischemia was thought to be responsible for the slow reduction in force (Abraham, Craig 1975). Conclusions based on previous findings vary from the current results in that all subjects in previous results have all produced a common pattern; they matched the negative pattern in the current work. Our results indicate that the decline in tension may be more complicated than previously proposed (Abraham, Craig 1975). It is possible that when subjects were cued to the initial force level their subconscious sensory perception was increased. This increased awareness of environmental cues may have augmented the anticipatory nature of the motor program and led to a more reliable muscular force output. Current results did not offer this environmental and sensory cue and may have directly influenced participant's reliability. As each subject was naïve to the protocol a large potential for learning is present and was indicated by changes within the LOA, the measurement that assessed day to day changes. Subjects were also asked to volunteer any general comments on the entire procedure; no associations were present between comments of awareness of changes in muscular force and the pattern to which an individual displayed. Overall, we speculate that each contraction increased the available 'past experiences' (Figure 3) and correspondingly increased the consistency of the motor output.

The use of both the MVC and indicator exercise before and after the product exercises were used as a tool to assess training effects. Validation of isometric training programs to increase strength is generally done with the comparison of an MVC before and after training (Duchateau, Hainaut 1984). In such studies an increase in MVC yields a successful program. Following our protocol 18 participants produced an MVC that was below the initial levels. While

this does not directly affect our interpretation of the product exercise it lends itself to the idea that fatigue accumulated throughout the week, and potentially became a factor. Other results without a training protocol have found isometric MVC of the knee extensors to produce reliable results when retested 7 days apart from one another (Maffiuletti et al. 2007). In addition, the perceived exertion during the constant force contractions was approximately one point higher after the 4 days of single contractions, thus subjects perceived the same exercise as more physiologically straining after the 4 days of exercise. Pincivero et al. (2003) showed that RPE is stable for a wide range of sub-maximal isometric contractions when tested 1 w later. It is more likely that both fatigue and the methods employed were responsible for our results. On day 1 the MVC was the first contraction whereas it was the third contraction on the day 4. Therefore, it is unknown whether the fatigue was due to an accumulated effect throughout the day or the week. In conclusion, the accumulation of fatigue may have directly affected reliability. More work is needed to determine if athletes are capable of reproducing the protocol with shorter (within days) and/or longer (between days) delays.

5.4 Changes in Blood Pressure

The autonomic nervous system regulates blood pressure via the control of total peripheral resistance and heart rate. Changes in BP during isometric exercise are relative to resting BP, which is further subject to age and body fat content (Petrofsky, Lind 1975). It has been shown that sub-maximal leg extensions held to fatigue demonstrate a continual rise in MAP (Smolander et al. 1998). Within our design all subjects had a similar level of effort, and therefore matched previous research with a similar increase in BP across subjects. One mechanism partially responsible for the magnitude of change in BP response during isometric contractions is the level of effort, regardless of force production (MacDougall et al. 1992). In a well designed study results suggested that the primary mechanism responsible for BP regulation during low-intensity isometric exercise is vasomotor tone (Fisher et al. 2006). In conclusion, these results lend

support to idea that conscious effects (voluntary effort) are capable of directly affecting autonomic processes.

5.5 Changes in Psychological Measurements

Self-efficacy was used to determine the belief in an individual's capability to perform a required action and generate the specific outcomes that are expected within that situation (Duda 1998). Therefore, SE measured prior to the activity quantified the participant's belief that they were able to maintain a constant perceived effort, regardless of force production. Although SE between 30, 90 and 120 s was shown to be statistically reduced, the practical relevance was considered negligible because their confidence was maintained above 91.44%. Interestingly, the change in SE was similar to the change in torque throughout the product exercise, as both decreased in a linear manner. In conclusion, it seems as though a correlation may exist between high SE and reliability of the isometric product exercise.

With respect to perceived exertion, previous evidence suggests that constant effort contractions both underestimate (Jackson, Dishman 2000) and overestimate force production (Pinciviero et al. 2003). The work of Pinciviero et al (2003) compared perceptually guided isometric contractions at several levels of MVC. Based on table 2 of their results, participants tend to overestimate force production at all levels above 10% MVC. The authors postulate that humans subconsciously avoid strenuous muscle contraction conditions by allowing the conscious awareness to believe that a more strenuous muscular action is being performed. The combination of high SE and underestimation of force production in the previous study further support the notion of this theory.

5.6 Practical Considerations and Future Directions

Use of a constant effort contraction allows for an alternative way of assessing neuromuscular fatigue. It creates an opportunity for cerebral processes to anticipate internal capacity and act accordingly and concomitant with conscious perceived exertion to influence our muscular output in a real time

basis. Such dynamic control of cerebral processes is thought to allow for the highest validity in a laboratory setting. The product exercise used within this experiment proved to be a reliable method to consistently produce a single neuromuscular output during isometric leg extensions; however large differences may need to be seen in order to attribute them to experimental techniques and not typical (biological, equipment, or statistical) error. Current work increased the influence of anticipatory mechanisms yet remained congruent to previous findings (Cain, Steven 1971; Doherty et al. 2001). Individuals are capable of producing reliable results across days when prompted to the initial torque or speed and asked to maintain their output (Cain, Stevens 1971; Buckley et al. 2000; Doherty et al. 2001). Furthermore, when participants are asked to reproduce – not maintain - torque within days reliable results have been found without prompting (Gros Lambert et al. 2002; West et al. 2005). As was mentioned earlier, no statistical measures have been reported on the reliability of a product exercise in an isometric environment. A slight learning effect was present when the data was assessed between days using the LOA. While more work is needed to determine the presence of and saturation point for the learning effect, the current protocol is capable of reliability under conditions of minimal learning. It is suggested that all participants undergo 3 familiarization sessions – done on separate days – prior to data collection. Within scientific research this design potentially allows for a viable and unique way to characterize the effect of neuromuscular learning. Our sample consisted of highly trained athletes that demonstrated a learning effect and future work may look to characterize changes in electrical activity of the muscle or cerebral processes of trained individuals.

Such results indicate that a single constant exertion is capable of generating consistent muscular outputs across days given that the appropriate guidelines are followed (Table. 2). During repeated isometric contractions within a single day participants should generate a torque without being prompted to a torque, yet not maintain the effort for any duration (West et al. 2005). During repeated isometric contractions across days two methods can be followed (i) participants should be prompted to a previous torque and asked to maintain such

an effort for up to 2.5 min in duration without the aid of external cues or, (ii) participants asked to produce a product exercise from a resting muscle (no cue provided) should be exposed to a minimum of 3 familiarization sessions prior to data collection. In addition, when asked to run at constant efforts on different day's participants can reliably produce and maintain running speeds without prompting (Doherty et al. 2001). The combination of previous and current work indicates that participants would be capable of producing reliable results in isometric contractions or other whole body exercises providing they are trained in the movements required for that skill using a single familiarization session.

	Protocol	Reference
Repeated contractions between days	Cue needed Maintain force No training needed	Cain Stevens 1971
	No cue Maintain force 3 training sessions needed	Current Work
Repeated Contractions Within Days	No cue needed Generate torque No training needed	Groslambert et al. 2002 West et al. 2005

Table 2. Guidelines for the further use of Isometric Contractions that are Perceptually Guided by the use of Constant Perceived Exertion

5.7 Limitations

When a large spread exists in the data it is more difficult for a correlation coefficient to detect differences. Therefore the R may indicate a higher reliability than is actually present (Atkinson, Nevill 1998). Furthermore, R contains the variance term for the individuals and is affected by the sample heterogeneity, thus a high correlation may still mean an unacceptable reliability (Atkinson, Nevill

1998). To best counteract these shortcomings of a correlation coefficient an absolute measure – LOA – was also employed (Atkinson, Nevill 1998). The limits are designed to overcome this weakness by assuming a population of individual test-retest differences (Bland, Altman 1999).

The RPE scale used in this protocol was designed for the whole body exercise, particularly cycling. Despite this the RPE scale has been thoroughly tested in many differentiated settings and is validated for use with single joints (Ekblom, Goldberg 1971; Pandolf et al. 1975). Moreover, the main impetus for its use within this design was the potential symbiosis of isometric and whole body exercise. We speculate that a single measure is capable of manipulating voluntary effort whether activating the muscles at a single joint, or coordinating muscles for dynamic whole body exercise. Moreover, the RPE that was employed in this study is a category measure designed for inter-individual comparisons, not intra-individual analysis. The drive behind using the 15 point category scale stems from the conditional purpose of the study – to extrapolate the constant effort test into isokinetic and whole body dynamic settings. In order to maintain a given perceived exertion in different environments the same scale will have to be used. Therefore the 15 point scale, which is widely used in whole body literature, was chosen to fit all modes of constant perceived exertion.

No measures were taken to ensure that the MVC that was performed before and after the data collection of the product exercise was truly maximal. The use of the ITT would have ensured that subjects were providing an “all-out” muscular contraction.

Appendix 1

The ratings of perceived exertion (**RPE**) takes into account all that you are perceiving in terms of fatigue, including psychological, musculoskeletal, and environmental factors. This level of perceived physical effort is assigned a rating from the scale below:

<u>RPE</u>	
6	
7	very, very light
8	
9	very light
10	
11	fairly light
12	
13	somewhat hard
14	
15	hard
16	
17	very hard
18	
19	very, very hard
20	

On this scale, an RPE of 12 to 13 corresponds to approximately 60 to 79 percent of maximal heart rate. An RPE of 16 would correspond to about 90 percent of maximal heart rate. Thus, as a rule, most persons would exercise between 12 and 16 on this scale.

Appendix 2

An explanation of the product exercise and the questions that were used for determination of the participant's SE.

Explanation of the product exercise

The main concept of this exercise is to have you [the participant] hold a specific internal or subjective intensity for 2 min. you will not receive any feedback from me [researcher] or the computer screen, the only sensation that I would like you to focus on is the sensation of perceived exertion that arises from your local musculature, that being your quadriceps.

The length of this exercise will be 2 min and you are to try to extend you leg at the knee (straighten your leg) for this duration. No external feedback of any sense will be given to you throughout the contraction; however you are encouraged to use whatever internal means necessary to maintain a consistent perceived exertion. The main idea of this exercise to maintain constant perceived effort. The magnitude of effort will be set to the average of the contraction that was just previously completed [indicator exercise].

Throughout the contraction, at random time points, I will be asking for your estimate of where you think your perceived exertion lies on the Borg RPE scale that you can see in front of you.

Do you have any questions before we start a trial run?

Determination of Self Efficacy

(1) How confident are you in your ability to sustain the sub-maximal contraction with visual feedback when the force is equal to 30% of your MVC for:

- (i) 30 s?
0 _____ 100
- (ii) 90 s?
0 _____ 100
- (iii) 120 s?
0 _____ 100

(2) How confident are you that you can maintain a perceived intensity of effort without any external feedback for:

- (i) 30 s?
0 _____ 100
- (ii) 90 s?
0 _____ 100
- (iii) 120 s?
0 _____ 100

Appendix 3

Force Time Scales.

These scales were used as a qualitative assessment for the perception of muscular activity during the product exercise.

“Now that you have completed 4 days of sequential constant effort contractions we are interested in gauging your perception of the force. If you were to set the force that you produced in the first few seconds of the contraction at 100% of force output please indicate how confident you are that you were able to maintain that exact level of force.”

1. How confident are you that you were able to maintain your force for 30 s?

0 ————— 100

2. How confident are you that you were able to maintain your force for 90 s?

0 ————— 100

3. How confident are you that you were able to maintain your force for 120 s?

0 ————— 100

6 References

- Abbiss, C.R. & Laursen, P.B. 2008, "Describing and Understanding Pacing Strategies during Athletic Competition", *Sports medicine (Auckland, N.Z.)*, vol. 38, no. 3, pp. 239-252.
- Abbiss, C.R. & Laursen, P.B. 2005, "Models to explain fatigue during prolonged endurance cycling", *Sports medicine (Auckland, N.Z.)*, vol. 35, no. 10, pp. 865-898.
- Abbiss, C.R., Quod, M.J., Martin, D.T., Netto, K.J., Nosaka, K., Lee, H., Surriano, R., Bishop, D. & Laursen, P.B. 2006, "Dynamic pacing strategies during the cycle phase of an Ironman triathlon", *Medicine and science in sports and exercise*, vol. 38, no. 4, pp. 726-734.
- Abraham, W.M. & Craig, A.B., Jr 1975, "Tension decline during isometric contractions without visual cues", *Medicine and science in sports*, vol. 7, no. 2, pp. 99-104.
- Atkinson, G. & Nevill, A.M. 1998, "Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine", *Sports medicine (Auckland, N.Z.)*, vol. 26, no. 4, pp. 217-238.
- Bigland-Ritchie, B., Furbush, F. & Woods, J.J. 1986, "Fatigue of intermittent submaximal voluntary contractions: central and peripheral factors", *Journal of applied physiology (Bethesda, Md.: 1985)*, vol. 61, no. 2, pp. 421-429.
- Binder, M.D., Kroin, J.S., Moore, G.P. & Stuart, D.G. 1977, "The response of Golgi tendon organs to single motor unit contractions", *The Journal of physiology*, vol. 271, no. 2, pp. 337-349.
- Blakemore, S.J., Frith, C.D. & Wolpert, D.M. 2001, "The cerebellum is involved in predicting the sensory consequences of action", *Neuroreport*, vol. 12, no. 9, pp. 1879-1884.
- Bland, J.M. & Altman, D.G. 1999, "Measuring agreement in method comparison studies", *Statistical methods in medical research*, vol. 8, no. 2, pp. 135-160.
- Bland, J.M. & Altman, D.G. 1986, "Statistical methods for assessing agreement between two methods of clinical measurement", *Lancet*, vol. 1, no. 8476, pp. 307-310.
- Borg, G., Hassmen, P. & Lagerstrom, M. 1987, "Perceived exertion related to heart rate and blood lactate during arm and leg exercise", *European journal of applied physiology and occupational physiology*, vol. 56, no. 6, pp. 679-685.

- Borg, G.A. 1982a, "Psychophysical bases of perceived exertion", *Medicine and science in sports and exercise*, vol. 14, no. 5, pp. 377-381.
- Buckley, J.P., Eston, R.G. & Sim, J. 2000, "Ratings of perceived exertion in braille: validity and reliability in production mode", *British journal of sports medicine*, vol. 34, no. 4, pp. 297-302.
- Cain, W.S. & Stevens, J.C. 1973a, "Constant-effort contractions related to the electromyogram", *Medicine and science in sports*, vol. 5, no. 2, pp. 121-127.
- Cain, W.S. & Stevens, J.C. 1971, "Effort in sustained and phasic handgrip contractions", *The American Journal of Psychology*, vol. 84, no. 1, pp. 52-65.
- Ceci, R. & Hassmen, P. 1991, "Self-monitored exercise at three different RPE intensities in treadmill vs field running", *Medicine and science in sports and exercise*, vol. 23, no. 6, pp. 732-738.
- Colombo, R., Mazzini, L., Mora, G., Parenzan, R., Creola, G., Pirali, I. & Minuco, G. 2000, "Measurement of isometric muscle strength: a reproducibility study of maximal voluntary contraction in normal subjects and amyotrophic lateral sclerosis patients", *Medical engineering & physics*, vol. 22, no. 3, pp. 167-174.
- Corty, E. 2007 *Using and Interpreting Statistics: A Practical text for the Health, Behavioral, and Social Sciences*, pp., 89-113, Mosby Elsevier.
- Crammond, D.J. & Kalaska, J.F. 1996, "Differential relation of discharge in primary motor cortex and premotor cortex to movements versus actively maintained postures during a reaching task", *Experimental brain research. Experimentelle Hirnforschung. Experimentation cerebrale*, vol. 108, no. 1, pp. 45-61.
- DeLuca, J. 1997, "The Use of Surface Electromyography in Biomechanics", *Journal of Applied Biomechanics*, vol. 13, no. 2, pp. 135.
- Doherty, M., Smith, P.M., Hughes, M.G. & Collins, D. 2001, "Rating of perceived exertion during high-intensity treadmill running", *Medicine and science in sports and exercise*, vol. 33, no. 11, pp. 1953-1958.
- Duchateau, J. & Hainaut, K. 1984, "Isometric or dynamic training: differential effects on mechanical properties of a human muscle", *Journal of applied physiology: respiratory, environmental and exercise physiology*, vol. 56, no. 2, pp. 296-301.
- Duda, J.L. 1998, *Advances in sport and exercise psychology measurement*, Fitness Information Technology, Morgantown, W. Va.

- Dunbar, C.C., Kalinski, M.I. & Robertson, R.J. 1996, "A new method for prescribing exercise: three-point ratings of perceived exertion", *Perceptual and motor skills*, vol. 82, no. 1, pp. 139-146.
- Dunbar, C.C., Robertson, R.J., Baun, R., Blandin, M.F., Metz, K., Burdett, R. & Goss, F.L. 1992, "The validity of regulating exercise intensity by ratings of perceived exertion", *Medicine and science in sports and exercise*, vol. 24, no. 1, pp. 94-99.
- Dunn, O. J., 2001, "*Basic Statistics: A Primer for the Biomedical Sciences*", pp. 71-86, Wiley.
- Eason, R. 1959 "The Surface Electromyogram (EMG) Gauges Subjective Effort" *Perceptual and Motor Skills*, vol. 9, pp. 359-361.
- Ekblom, B., Goldberg, A. 1971, "The influence of physical training and other factors on the subjective rating of perceived exertion", *Acta Physiologica Scandinavica*, vol. 83, pp. 399.
- Elder, G.C., Bradbury, K. & Roberts, R. 1982, "Variability of fiber type distributions within human muscles", *Journal of applied physiology: respiratory, environmental and exercise physiology*, vol. 53, no. 6, pp. 1473-1480.
- Emes, C.G. 1979, "Maintenance of uncued isometric contractions by blind and sighted", *Perceptual and motor skills*, vol. 49, no. 2, pp. 475-479.
- Eston, R.G., Davies, B.L. & Williams, J.G. 1987, "Use of perceived effort ratings to control exercise intensity in young healthy adults", *European journal of applied physiology and occupational physiology*, vol. 56, no. 2, pp. 222-224.
- Eston, R.G. & Williams, J.G. 1988, "Reliability of ratings of perceived effort regulation of exercise intensity", *British journal of sports medicine*, vol. 22, no. 4, pp. 153-155.
- Fallentin, N., Jorgensen, K. & Simonsen, E.B. 1993, "Motor unit recruitment during prolonged isometric contractions", *European journal of applied physiology and occupational physiology*, vol. 67, no. 4, pp. 335-341.
- Fisher, J.P., Ogoh, S., Dawson, E.A., Fadel, P.J., Secher, N.H., Raven, P.B. & White, M.J. 2006, "Cardiac and vasomotor components of the carotid baroreflex control of arterial blood pressure during isometric exercise in humans", *The Journal of physiology*, vol. 572, no. Pt 3, pp. 869-880.
- Fromm, C. & Evarts, E.V. 1982, "Pyramidal tract neurons in somatosensory cortex: central and peripheral inputs during voluntary movement", *Brain research*, vol. 238, no. 1, pp. 186-191.

- Gandevia, S.C. & McKenzie, D.K. 1988, "Activation of human muscles at short muscle lengths during maximal static efforts", *The Journal of physiology*, vol. 407, pp. 599-613.
- Gearhart, R.F., Jr, Becque, M.D., Hutchins, M.D. & Palm, C.M. 2004, "Comparison of memory and combined exercise and memory-anchoring procedures on ratings of perceived exertion during short duration, near-peak-intensity cycle ergometer exercise", *Perceptual and motor skills*, vol. 99, no. 3 Pt 1, pp. 775-784.
- Gregory, J.E., Brockett, C.L., Morgan, D.L., Whitehead, N.P. & Proske, U. 2002, "Effect of eccentric muscle contractions on Golgi tendon organ responses to passive and active tension in the cat", *The Journal of physiology*, vol. 538, no. Pt 1, pp. 209-218.
- Gros Lambert, A., Nachon, M. & Rouillon, J.D. 2002, "Influence of the age on self regulation of static grip forces from perceived exertion values", *Neuroscience letters*, vol. 325, no. 1, pp. 52-56.
- Henneman, E. 1957, "Relation between size of neurons and their susceptibility to discharge", *Science (New York, N.Y.)*, vol. 126, no. 3287, pp. 1345-1347.
- Hopkins, W.G. 2000, "Measures of reliability in sports medicine and science", *Sports medicine (Auckland, N.Z.)*, vol. 30, no. 1, pp. 1-15.
- Jackson, A.W. & Dishman, R.K. 2000, "Perceived submaximal force production in young adult males and females", *Medicine and science in sports and exercise*, vol. 32, no. 2, pp. 448-451.
- Jones, L.A. & Hunter, I.W. 1983, "Force and EMG correlates of constant effort contractions", *European journal of applied physiology and occupational physiology*, vol. 51, no. 1, pp. 75-83.
- Kayser, B. 2003, "Exercise starts and ends in the brain", *European journal of applied physiology*, vol. 90, no. 3-4, pp. 411-419.
- Lamb, K.L., Eston, R.G. & Corns, D. 1999, "Reliability of ratings of perceived exertion during progressive treadmill exercise", *British journal of sports medicine*, vol. 33, no. 5, pp. 336-339.
- Lucas, S.J., Anglem, N., Roberts, W.S., Anson, J.G., Palmer, C.D., Walker, R.J., Cook, C.J. & Cotter, J.D. 2008, "Intensity and physiological strain of competitive ultra-endurance exercise in humans", *Journal of sports sciences*, vol. 26, no. 5, pp. 477-489.
- MacDougall, J.D., McKelvie, R.S., Moroz, D.E., Sale, D.G., McCartney, N. & Buick, F. 1992, "Factors affecting blood pressure during heavy weight lifting

- and static contractions", *Journal of applied physiology (Bethesda, Md.: 1985)*, vol. 73, no. 4, pp. 1590-1597.
- Maffiuletti, N.A., Bizzini, M., Desbrosses, K., Babault, N. & Munzinger, U. 2007, "Reliability of knee extension and flexion measurements using the Con-Trex isokinetic dynamometer", *Clinical physiology and functional imaging*, vol. 27, no. 6, pp. 346-353.
- McArdle, W.D., Katch, F.I. & Katch, V.L. 2001, *Exercise Physiology Energy Nutrition and Human Performance*, Liipincott Williams & Wilkins, Baltimore, Maryland.
- Merton, P.A. 1954, "Voluntary strength and fatigue", *The Journal of physiology*, vol. 123, no. 3, pp. 553-564.
- Mihevici, P.M. 1981, "Sensory cues for perceived exertion: a review", *Medicine and science in sports and exercise*, vol. 13, no. 3, pp. 150-163.
- Mima, T., Sadato, N., Yazawa, S., Hanakawa, T., Fukuyama, H., Yonekura, Y. & Shibasaki, H. 1999, "Brain structures related to active and passive finger movements in man", *Brain : a journal of neurology*, vol. 122 (Pt 10), no. Pt 10, pp. 1989-1997.
- Mitchell, L.A., MacDonald, R.A. & Brodie, E.E. 2004, "Temperature and the cold pressor test", *The journal of pain : official journal of the American Pain Society*, vol. 5, no. 4, pp. 233-237.
- Morrison, S., Sleivert, G.G. & Cheung, S.S. 2004, "Passive hyperthermia reduces voluntary activation and isometric force production", *European journal of applied physiology*, vol. 91, no. 5-6, pp. 729-736.
- Morton, J.P., Atkinson, G., MacLaren, D.P., Cable, N.T., Gilbert, G., Broome, C., McArdle, A. & Drust, B. 2005, "Reliability of maximal muscle force and voluntary activation as markers of exercise-induced muscle damage", *European journal of applied physiology*, vol. 94, no. 5-6, pp. 541-548.
- Natio, E., Roland, P., Ehrsson, H. 2002, "I Feel My Hand Moving: A New Role for the Primary Motor Cortex in Somatic Perception of Limb Movement", *Neuron*, vol. 36, pp. 979-988
- Nelson, R.J. 1996, "Interactions between motor commands and somatic perception in sensorimotor cortex", *Current opinion in neurobiology*, vol. 6, no. 6, pp. 801-810.
- Newham, D.J., McCarthy, T. & Turner, J. 1991, "Voluntary activation of human quadriceps during and after isokinetic exercise", *Journal of applied physiology (Bethesda, Md.: 1985)*, vol. 71, no. 6, pp. 2122-2126.

- Nigg, B., Herzog, W. (ed) 1999, *Biomechanics of the Musculo-Skeletal System*, Wiley.
- Noakes, T.D. 2007, "The central governor model of exercise regulation applied to the marathon", *Sports medicine (Auckland, N.Z.)*, vol. 37, no. 4-5, pp. 374-377.
- Noakes, T.D., Peltonen, J.E. & Rusko, H.K. 2001, "Evidence that a central governor regulates exercise performance during acute hypoxia and hyperoxia", *The Journal of experimental biology*, vol. 204, no. Pt 18, pp. 3225-3234.
- Noble, B.J., Borg, G.A., Jacobs, I., Ceci, R. & Kaiser, P. 1983, "A category-ratio perceived exertion scale: relationship to blood and muscle lactates and heart rate", *Medicine and science in sports and exercise*, vol. 15, no. 6, pp. 523-528.
- Pandolf, K.B. 1978, "Influence of local and central factors in dominating rated perceived exertion during physical work", *Perceptual and motor skills*, vol. 46, no. 3 Pt 1, pp. 683-698.
- Pandolf, K.B., Burse, R.L. & Goldman, R.F. 1975, "Differentiated ratings of perceived exertion during physical conditioning of older individuals using leg-weight loading", *Perceptual and motor skills*, vol. 40, no. 2, pp. 563-574.
- Pandolf, K.B. & Cain, W.S. 1974, "Constant Effort During Static and Dynamic Contractions", *Journal of Motor Behavior*, vol. 6, no. 2, pp. 101.
- Petrofsky, J.S. & Lind, A.R. 1975, "Isometric strength, endurance, and the blood pressure and heart rate responses during isometric exercise in healthy men and women, with special reference to age and body fat content", *Pflugers Archiv : European journal of physiology*, vol. 360, no. 1, pp. 49-61.
- Pincivero, D.M., Campy, R.M. & Coelho, A.J. 2003, "Knee flexor torque and perceived exertion: a gender and reliability analysis", *Medicine and science in sports and exercise*, vol. 35, no. 10, pp. 1720-1726.
- Plaskett, C.J. & Cafarelli, E. 2001, "Caffeine increases endurance and attenuates force sensation during submaximal isometric contractions", *Journal of applied physiology (Bethesda, Md.: 1985)*, vol. 91, no. 4, pp. 1535-1544.
- Prinz, W. 1997, "Perception and Action Planning", *European Journal of Cognitive Psychology*, vol. 9, no. 1, pp. 129-154.
- Rauch, H.G., St Clair Gibson, A., Lambert, E.V. & Noakes, T.D. 2005, "A signalling role for muscle glycogen in the regulation of pace during prolonged exercise", *British journal of sports medicine*, vol. 39, no. 1, pp. 34-38.

- Robertson, R.J., Gillespie, R.L., McCarthy, J. & Rose, K.D. 1979, "Differentiated perceptions of exertion: part II. relationship to local and central physiological responses", *Perceptual and motor skills*, vol. 49, no. 3, pp. 691-697.
- Roland, P.E., Skinhoj, E., Lassen, N.A. & Larsen, B. 1980, "Different cortical areas in man in organization of voluntary movements in extrapersonal space", *Journal of Neurophysiology*, vol. 43, no. 1, pp. 137-150.
- Roll, J.P. & Vedel, J.P. 1982, "Kinaesthetic role of muscle afferents in man, studied by tendon vibration and microneurography", *Experimental brain research. Experimentelle Hirnforschung. Experimentation cerebrale*, vol. 47, no. 2, pp. 177-190.
- Safrit, M., Atwater, A., Baumgartner, T., West, C. 1976, "Reliability Theory" AAHPER.
- Sainburg, R.L., Ghilardi, M.F., Poizner, H. & Ghez, C. 1995, "Control of limb dynamics in normal subjects and patients without proprioception", *Journal of neurophysiology*, vol. 73, no. 2, pp. 820-835.
- Sherwood, L. 2003, *Human Physiology: From Cells to Systems*, Brooks Cole.
- Smolander, J., Aminoff, T., Korhonen, I., Tervo, M., Shen, N., Korhonen, O. & Louhevaara, V. 1998, "Heart rate and blood pressure responses to isometric exercise in young and older men", *European journal of applied physiology and occupational physiology*, vol. 77, no. 5, pp. 439-444.
- St Clair Gibson, A., Lambert, M.L. & Noakes, T.D. 2001, "Neural control of force output during maximal and submaximal exercise", *Sports medicine (Auckland, N.Z.)*, vol. 31, no. 9, pp. 637-650.
- St Clair Gibson, A. & Noakes, T.D. 2004, "Evidence for complex system integration and dynamic neural regulation of skeletal muscle recruitment during exercise in humans", *British journal of sports medicine*, vol. 38, no. 6, pp. 797-806.
- Taylor, J.L. & Gandevia, S.C. 2008, "A comparison of central aspects of fatigue in submaximal and maximal voluntary contractions", *Journal of applied physiology (Bethesda, Md.: 1985)*, vol. 104, no. 2, pp. 542-550.
- Thepaut-Mathieu, C., Van Hoecke, J. & Maton, B. 1988, "Myoelectrical and mechanical changes linked to length specificity during isometric training", *Journal of applied physiology (Bethesda, Md.: 1985)*, vol. 64, no. 4, pp. 1500-1505.
- Thomas, M.M., Cheung, S.S., Elder, G.C. & Sleivert, G.G. 2006, "Voluntary muscle activation is impaired by core temperature rather than local muscle

temperature", *Journal of applied physiology* (Bethesda, Md.: 1985), vol. 100, no. 4, pp. 1361-1369.

Todd, G., Taylor, J.L. & Gandevia, S.C. 2003, "Measurement of voluntary activation of fresh and fatigued human muscles using transcranial magnetic stimulation", *The Journal of physiology*, vol. 551, no. Pt 2, pp. 661-671.

Todorov, E. & Jordan, M.I. 2002, "Optimal feedback control as a theory of motor coordination", *Nature neuroscience*, vol. 5, no. 11, pp. 1226-1235.

Tucker, R., Marle, T., Lambert, E.V. & Noakes, T.D. 2006, "The rate of heat storage mediates an anticipatory reduction in exercise intensity during cycling at a fixed rating of perceived exertion", *The Journal of physiology*, vol. 574, no. Pt 3, pp. 905-915.

Ulmer, H.V. 1996, "Concept of an extracellular regulation of muscular metabolic rate during heavy exercise in humans by psychophysiological feedback", *Experientia*, vol. 52, no. 5, pp. 416-420.

Weir, J.P. 2005, "Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM", *Journal of strength and conditioning research / National Strength & Conditioning Association*, vol. 19, no. 1, pp. 231-240.

West, S.J., Smith, L., Lambert, E.V., Noakes, T.D. & St Clair Gibson, A. 2005, "Submaximal force production during perceptually guided isometric exercise", *European journal of applied physiology*, vol. 95, no. 5-6, pp. 537-542.